Step

e.1. From figure 67, the entire Duck River basin is located in the smooth terrain zone. Therefore, there is no terrain adjustment factor for this example and the answers obtained in step 3-8d are the appropriate basin-averaged PMP for the Duck River basin.

f. Determine the TVA precipitation for the basin.

Since the basin is located in the entirely "smooth" terrain, the PMP values in step 8a are multiplied by the factor 0.53, which is the ratio of "smooth" TVA precipitation to "smooth" PMP precipitation-valid from 6 to 72 hr. Therefore, the resulting basin-averaged TVA precipitation for the Duck River basin is:

Dur. (hr.)	6	12	18	24	30	36	42	48	54	60	66	72
TVA prec. (in.)	6.8	8.5	9.7	10.8	11.4	12.0	12.5	12.8	13.0	13.2	13.4	13.6

By multiplying the isohyet values in table 17 by 0.53, one obtains the isohyetal depths representing the areal distribution of the TVA precipitation for the Duck River basin. This is shown in the following table:

Isohyet values (in.) for TVA precipitation in Duck River example

	6-hr periods											
Isohyet	1	2	3	4	5	6	7	8	9	10	11	12
A	10.90	1.96	1.27	1.06	0.64	0.53	0.48	0.32	0.27	0.27	0.21	0.21
B	10.23	1.89	1.26	1.06	0.64	0.53	0.48	0.32	0.27	0.27	0.21	0.21
C	9.56	1.84	1.24	1.06	0.64	0.53	0.48	0.32	0.27	0.27	0.21	0.21
D	8.88	1.79	1.23	1.06	0.64	0.53	0.48	0.32	0.27	0.27	0.21	0.21
E	8.21	1.75	1.22	1.06	0.64	0.53	0.48	0.32	0.27	0.27	0.21	0.21
F	7.57	1.72	1.22	1.06	0.64	0.53	0.48	0.32	0.27	0.27	0.21	0.21
G	7.03	1.69	1.21	1.06	0.64	0.53	0.48	0.32	0.27	0.27	0.21	0.21
H	6.46	1.65	1.21	1.06	0.64	0.53	0.48	0.32	0.27	0.27	0.21	0.21
I	5.96	1.62	1.20	1.06	0.64	0.53	0.48	0.32	0.27	0.27	0.21	0.21
J	5.38	1.58	1.20	1.06	0.64	0.53	0.48	0.32	0.27	0.27	0.21	0.21
K	3.77	1.26	0.99	0.86	0.51	0.43	0.39	0.26	0.22	0.22	0.17	0.17

5.5.5. Areal Distribution of Large-Basin PMP and Concurrent Basin Precipitation in the Mountainous East

The basin chosen for this example is the Little Tennessee River drainage above Franklin, TN considered in section 5.5.3 and shown as subbasin 8 along with concurrent basins in figure 92. This portion of the example continues the procedure by areally distributing the basin-averaged total PMP, and considers as well, the precipitation amounts that occur on selected concurrent basins (A, B, C, and D in fig. 92). The example makes use of procedures in sections 5.4.1, 5.4.2, and 5.4.4.2.

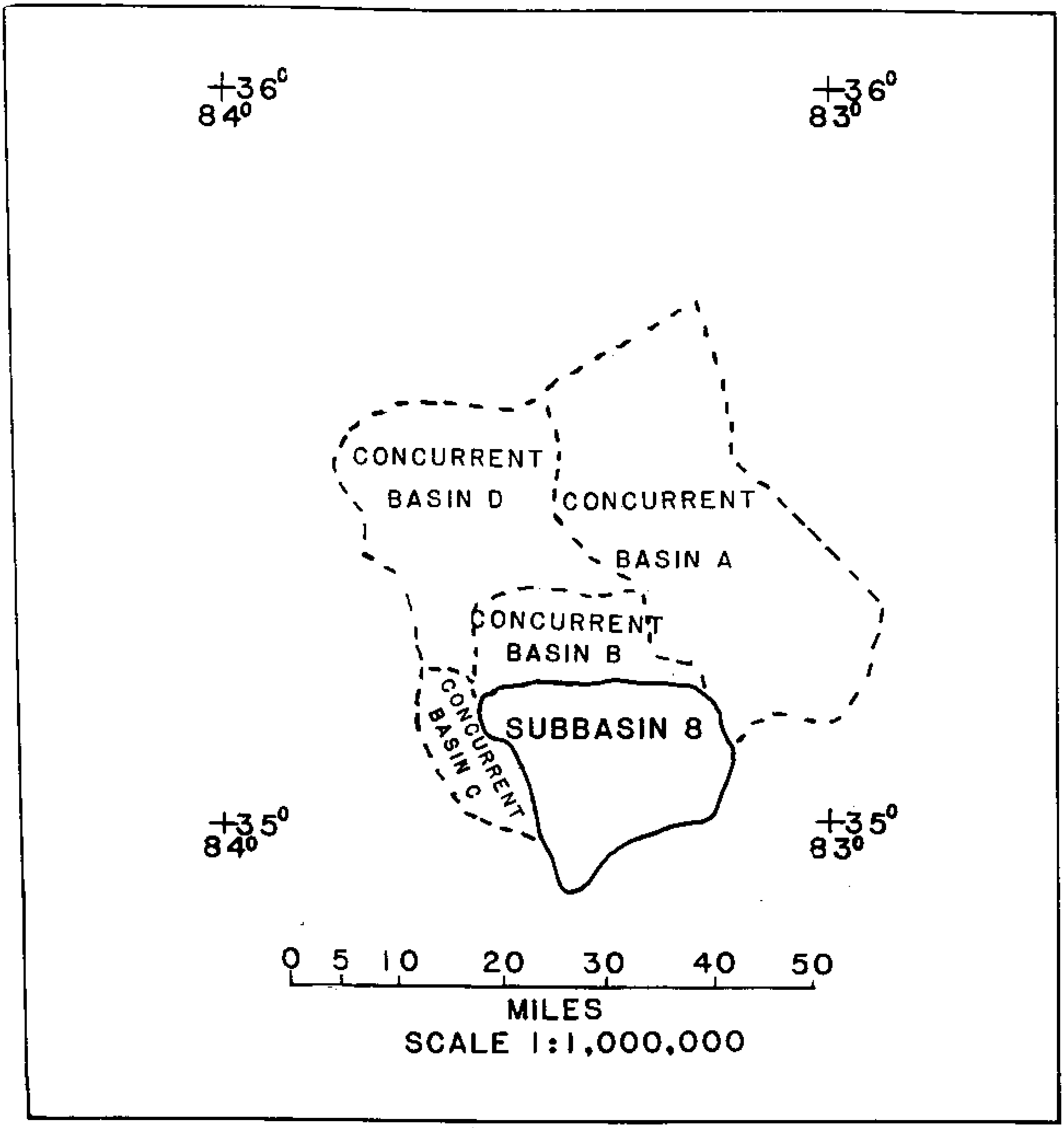

Figure 92.--Concurrent basins relative to Little Tennessee River basin.

<u>Step</u> (for areal distribution sect. 5.4.2) 6.3

1. Determine basin-centered total PMP pattern and isohyetal values from section 5.4 and 5.4.1 steps 1 to 8c.

    1-1. Place the idealized isohyetal pattern from figure 67 on the primary drainage with an orientation that will give maximum volume in the drainage (fig. 93).

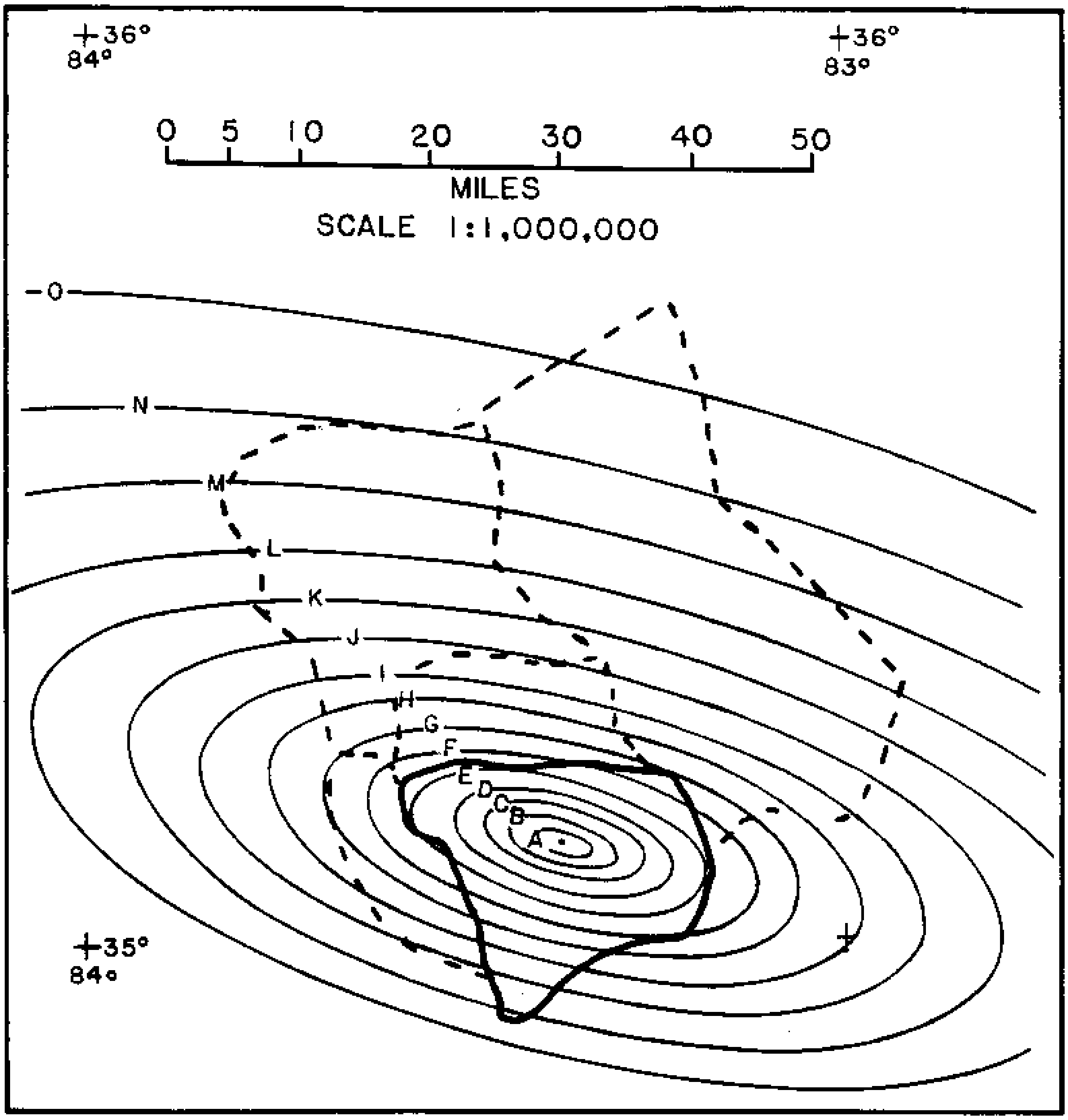

Figure 93.--Elliptical pattern centered over the Little Tennessee River drainage.

Table 18.--Isohyet values (in.) for total PMP for the Little Tennessee River basin.

Isohyet	1	2	3	4	5	6	7	8	9	10	11	12
A	29.42	4.86	2.44	2.20	1.80	1.50	1.00	1.00	0.90	0.70	0.60	0.60
B	27.53	4.69	2.41	2.20	1.80	1.50	1.00	1.00	0.90	0.70	0.60	0.60
C	25.75	4.52	2.38	2.20	1.80	1.50	1.00	1.00	0.90	0.70	0.60	0.60
D	23.98	4.39	2.36	2.20	1.80	1.50	1.00	1.00	0.90	0.70	0.60	0.60
E	22.42	4.28	2.35	2.20	1.80	1.50	1.00	1.00	0.90	0.70	0.60	0.60
F	20.65	4.17	2.34	2.20	1.80	1.50	1.00	1.00	0.90	0.70	0.60	0.60
G	19.09	4.09	2.33	2.20	1.80	1.50	1.00	1.00	0.90	0.70	0.60	0.60
H	13.99	3.33	1.97	1.85	1.51	1.26	0.84	0.84	0.76	0.59	0.50	0.50
I	11.10	2.84	1.67	1.56	1.28	1.07	0.71	0.71	0.64	0.50	0.43	0.43
J	8.55	2.37	1.41	1.32	1.08	0.90	0.60	0.60	0.54	0.42	0.36	0.36
K	6.66	1.94	1.18	1.10	0.90	0.75	0.50	0.50	0.45	0.35	0.30	0.30
L	5.11	1.57	0.93	0.87	0.71	0.59	0.40	0.40	0.36	0.28	0.24	0.24
M	3.33	1.10	0.71	0.66	0.54	0.45	0.30	0.30	0.27	0.21	0.18	0.18
N	1.78	0.60	0.45	0.42	0.34	0.29	0.19	0.19	0.17	0.13	0.11	0.11
O	0.67	0.19	0.16	0.15	0.13	0.11	0.07	0.07	0.06	0.05	0.04	0.04

1-2 to 1-8. Details of the computation to find the area of the PMP storm that gives maximum volume are not given here, as they are lengthy and follow closely those already exhibited in section 5.4.1. The TAF for subbasin 8 was computed to be 1.35 (sect. 5.5.3).

From this procedure, it was determined that a PMP storm area size of 450 mi^2 produced the maximum volume in the 295-mi^2 Little Tennessee River basin. As a result, isohyets A to G represent the PMP storm in figure 92 and isohyets H to O are residual precipitation. Values for total PMP for each 6-hr increment are given in table 18.

2. Adjust the basin-centered pattern toward the location of maximum 2-yr 24-hr amount in the basin. From figure 59, for the Little Tennessee River basin, this would be toward the southwest; however, since the basin is so small and because of the condition to limit displacement to 10 mi inside the basin boundary, no displacement is given for this example.

3. Because concurrent basins are of interest, and these are shown in figure 92 for this example, consider the steps in section 5.4.4.2. Expand the isohyetal pattern to cover the primary and concurrent basins as shown in figure 93.

3-1. The TAF from the procedure outlined in section 5.5.3 for the primary basin gives 1.35; and must be determined for each concurrent basin (sect. 5.4.3.2). Since computation of the TAF was detailed in step 6 of section 5.5.3, it was not repeated here. The TAF for each concurrent basin is divided by the TAF for the primary basin. Note that because the total area of primary plus concurrent basins exceeds 500 mi^2, the maximum adjustment of 0.25 from figure 66 is used to adjust the TAF in the concurrent basins. Refer to table 19 for these results.

3-2. To determine the warping factor, W, it is first necessary to convert the 2-yr 24-hr analysis in figure 94 (taken from fig. 59) to a percentage analysis. The center of the isohyetal pattern in figure 93 is 3.4 in. in figure 94. Dividing all the 2-yr 24-hr isohyets in figure 94 by 3.4 results in the isopercental analysis shown in figure 95.

The primary basin and each subbasin in figure 95 were planimetered to obtain average percentage values; 1.139 for the primary basin, 0.902 for subbasin A, 0.843 for subbasin B, 1.042 for subbasin C, and 0.829 for subbasin D. Taking the inverse of those average percentage values gives the respective values for W as listed in column 4 of table 19.

3-3. Since the pattern was not displaced in the example it is not necessary to adjust the isohyet values.

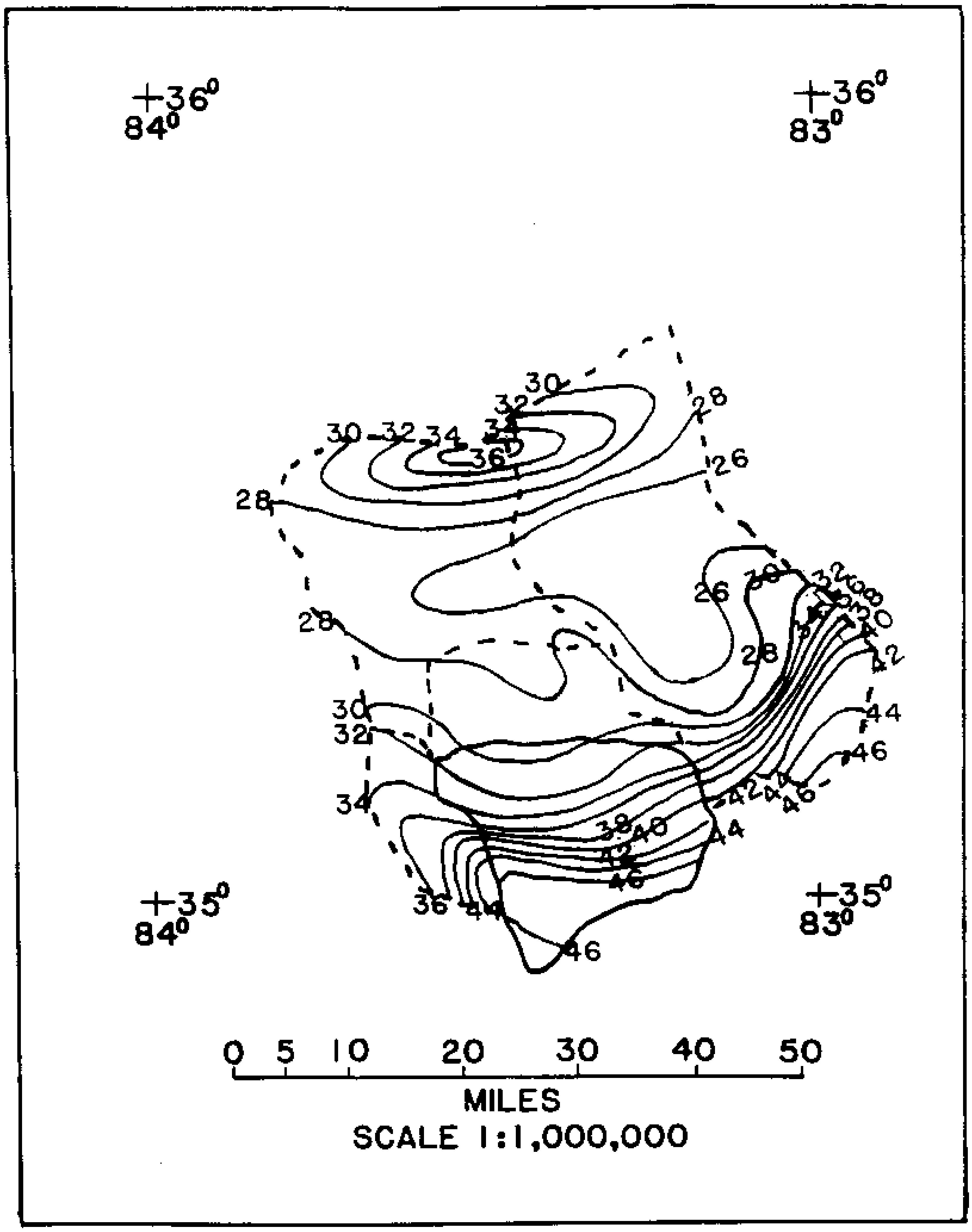

Figure 94.--2-yr 24-hr analysis that covers primary and concurrent basins (Reproduced from fig. 59). Note that all values are in tenths of an inch and have been multiplied by 10.

3-4. Multiply the total PMP isohyets in step 1-2 in each of the concurrent basins by the respective adjusted TAF's. Planimeter the adjusted isohyets to determine the incremental total volume for each concurrent basin, which is designated as V_x. Values of V_x for this example are summarized in column 4 of table 19.

3-5. Graphically multiply the orographically adjusted isohyet labels in step 3-4 by the isopercental analysis from step 3-2 (fig. 95).

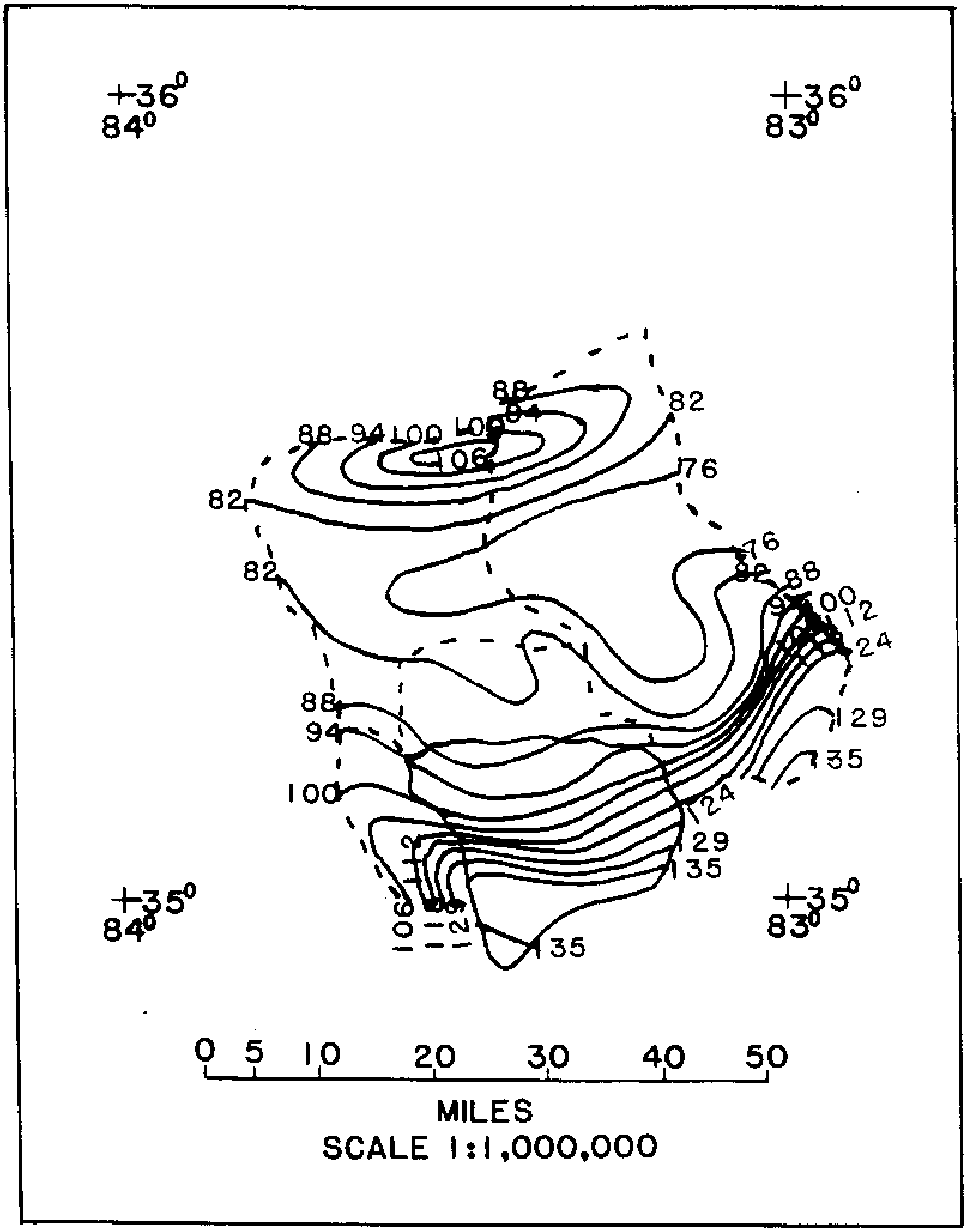

Figure 95.--Isopercental analysis of 2-yr 24-hr precipitation for primary and concurrent basins.

3-6. Analyze the results in step 3-5, as shown in figure 96 for this example. Note the discontinuities along basin boundaries. Adjust to maintain the volume given by the respective V_x for each basin in step 3-4 by multiplying the isohyets in figure 96 by the respective warping factor, W, from step 3-2. The warped isohyetal pattern adjusted by W and smoothed to remove the discontinuities is shown in figure 97. If the smoothing is believed to

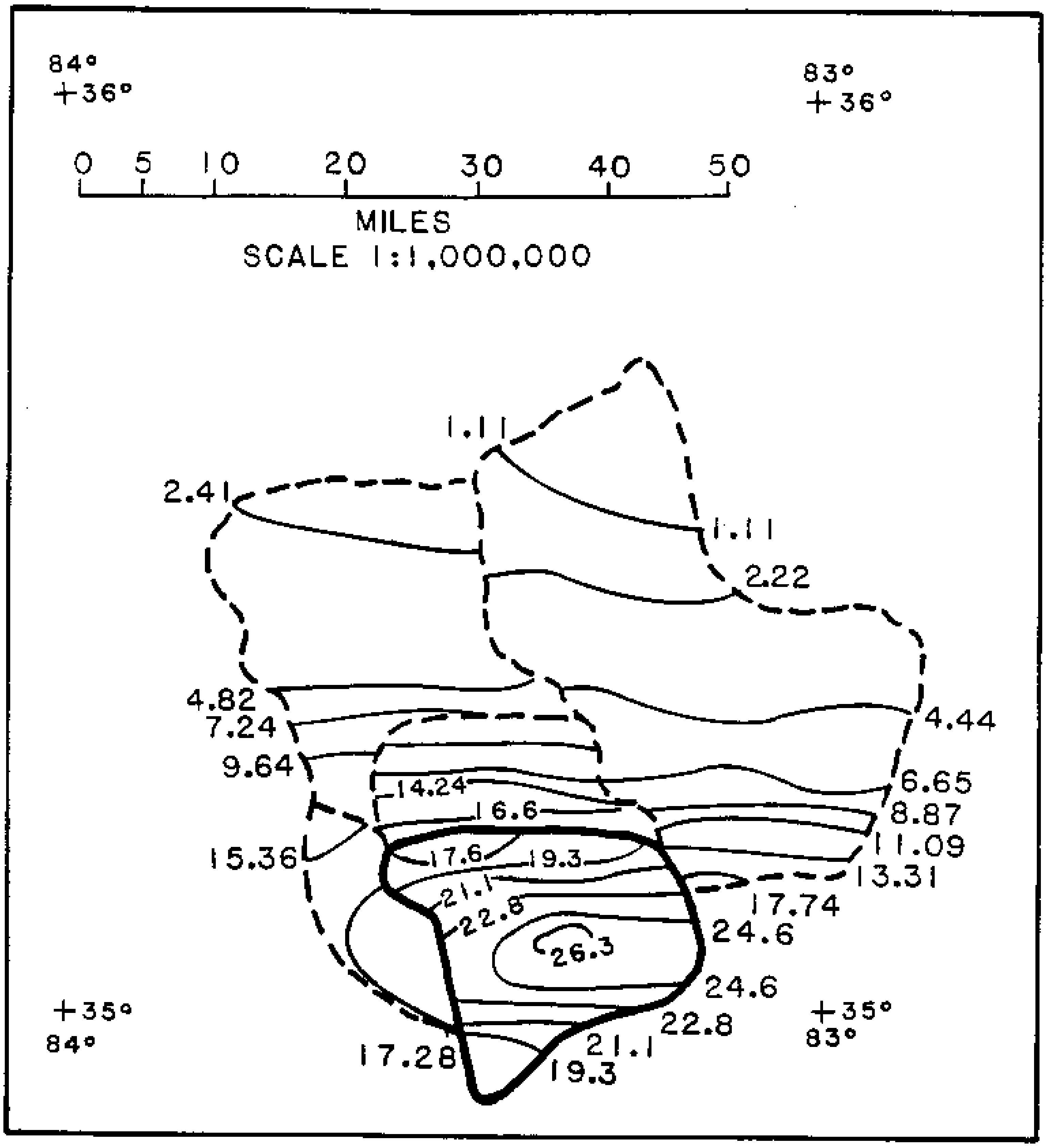

Figure 96.--Warped orographically adjusted pattern of total PMP (in.), first 6-hr increment for primary and concurrent basins. Notice the discontinuities of interfaces of subbasins.

Table 19.--Total volumetric precipitation for Little Tennessee River (subbasin 8) and concurrent basins, first 6-hr increment

Basin	Area (mi^2)	TAF	Adjusted TAF*	Total Volumetric Precipitation (V_x)	W
8	295	1.35	-	6771.62	0.878
A	655	1.10	0.81	2917.31	1.109
B	141	1.00	0.74	1620.77	1.186
C	91	1.15	0.85	1248.26	0.960
D	389	1.05	0.78	1805.43	1.206

* For concurrent basins in the mountainous east, the adjusted TAF is the TAF for the concurrent basin divided by the TAF for the primary basin; in this case TAF for the primary basin is 1.35.

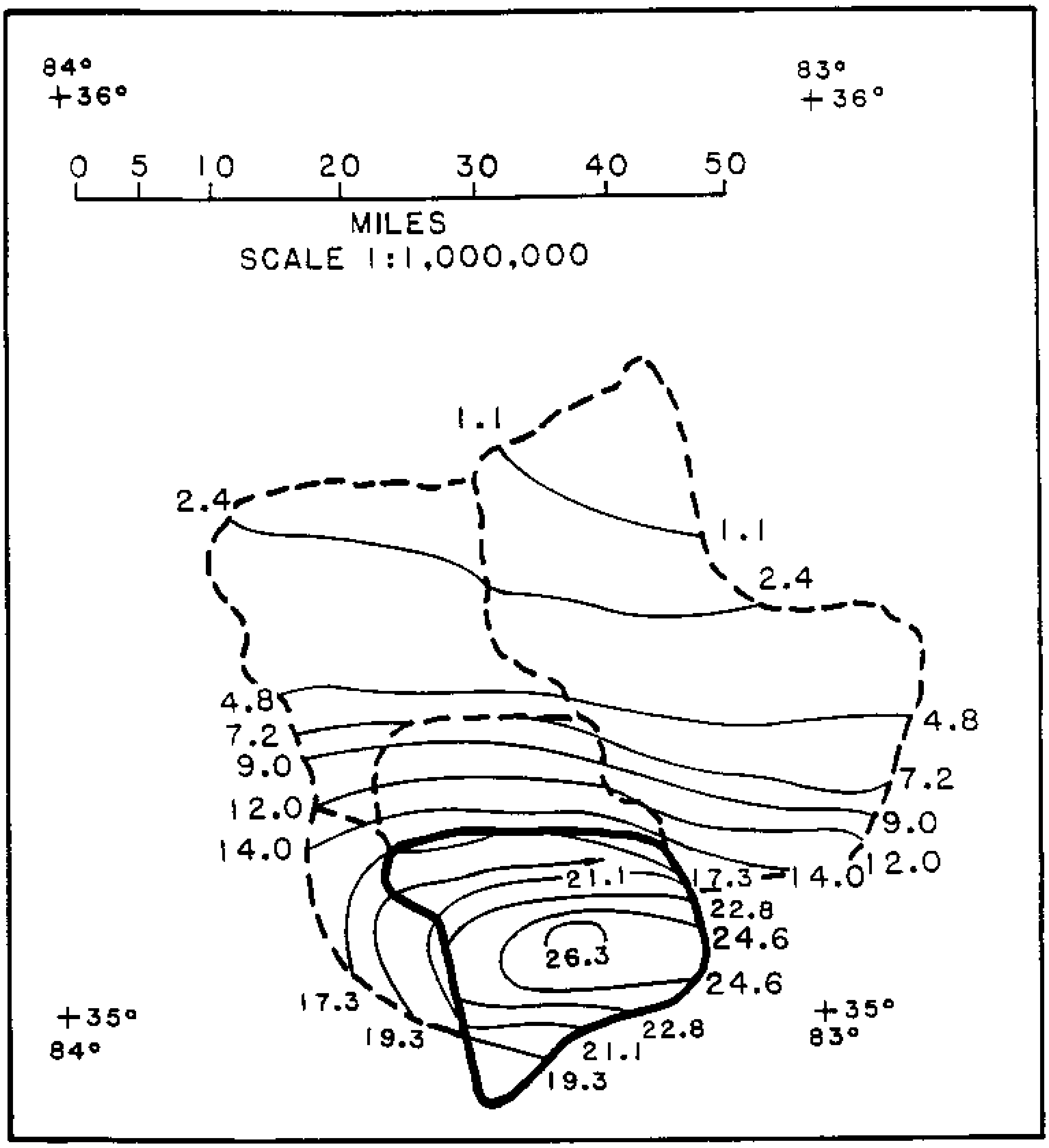

Figure 97.--Smoothed pattern of total PMP (in.), first 6-hr increment.

significantly change the volume, it may be necessary to replanimeter and adjust the isohyet values to maintain the volume, V_x (note that the adjusted isohyets have decimal values; it is not recommended to evaluate the pattern for whole numbers).

The values for TAF, W, and V_x for the second 6-hr increment are given in table 20, while figures 98 and 99 show the orographically adjusted warped and the smoothed patterns after modifying by W, respectively, for the second increment. Similar treatment (not shown here) is necessary for the other 6-hr increments to complete the example.

This example attempts to show the treatment recommended for concurrent basins, as well as the overall determination of areally distributed PMP for a basin in the mountainous east.

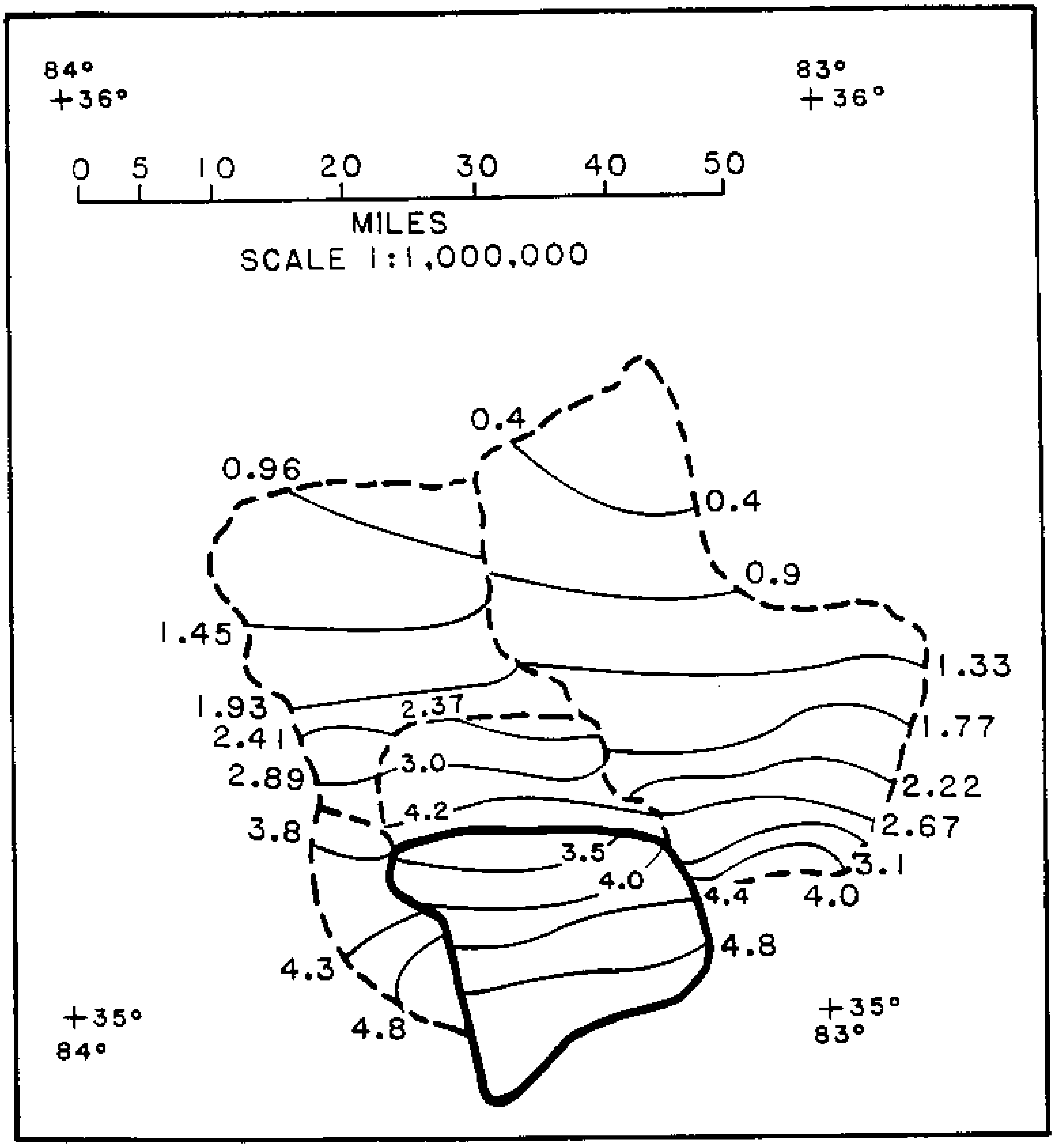

Figure 98.—Warped orographically adjusted pattern of total PMP (in.), second 6-hr increment.

3-7. Since both the primary and concurrent basins are located in the mountainous eastern portion of the watershed and are considered "rough," the smoothed total PMP isohyetal values obtained in step 3-6 are multiplied by 0.58 to obtain the areal distribution of TVA precipitation. These results are not shown.

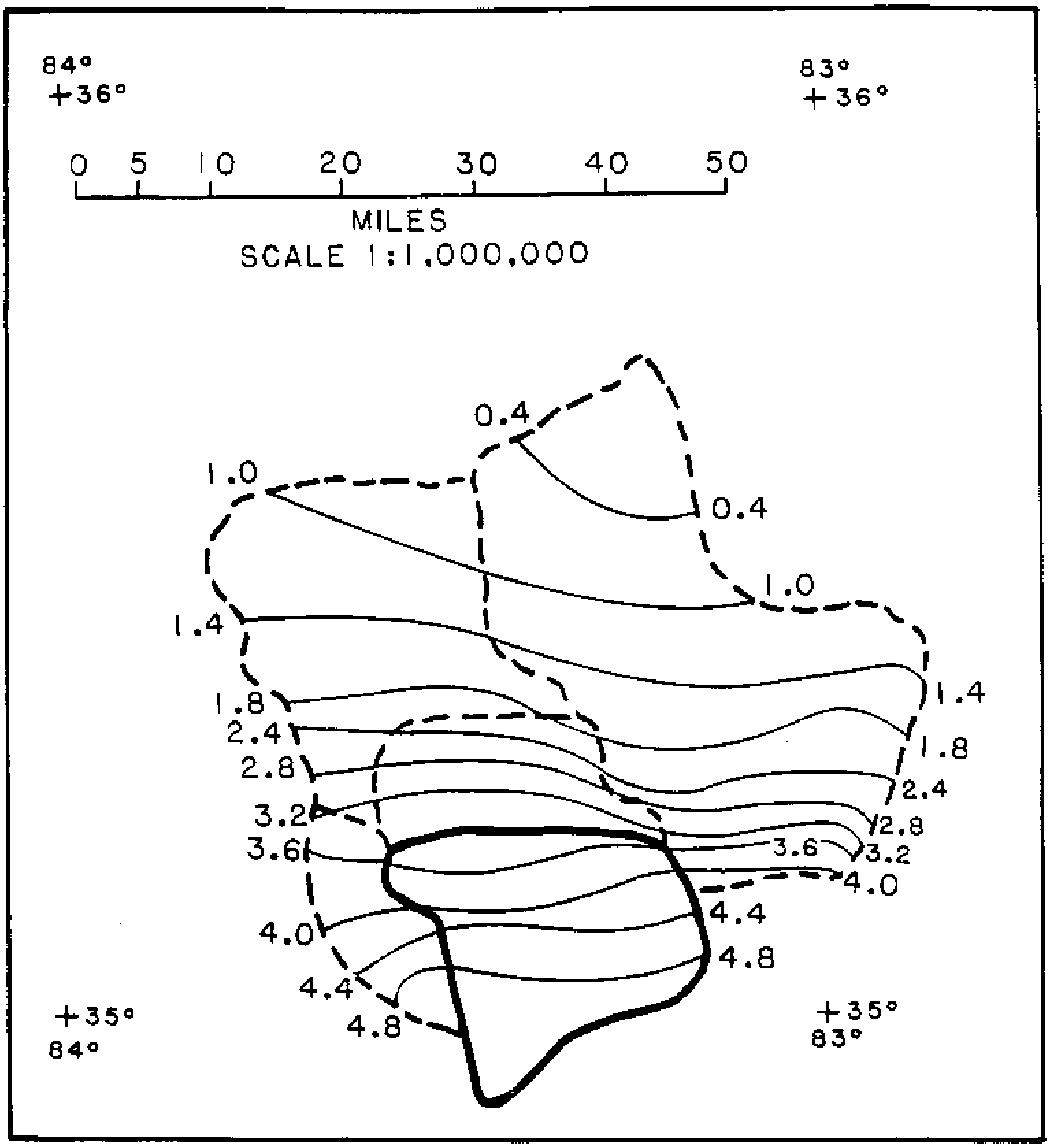

Figure 99.--Smoothed pattern of total PMP (in.), second 6-hr increment.

Table 20.--Total volumetric precipitation for Little Tennessee River (subbasin 8) and concurrent basins, second 6-hr increment

Basin	Area (mi^2)	TAF	Adjusted TAF*	Total Volumetric Precipitation (V_x)	W
8	295	1.35	-	1291.91	0.878
A	655	1.10	0.81	827.35	1.109
B	141	1.00	0.74	369.85	1.186
C	91	1.15	0.85	266.69	0.96
D	389	1.05	0.78	516.57	1.206

* For concurrent basins in the mountainous east, the adjusted TAF is the TAF for the concurrent basin divided by the TAF for the primary basin; in this case TAF for the primary basin is 1.35.

Table 21.—Terrain and orographic factors for basins located in mountainous and nonmountainous east portions of the Tennessee River watershed.

Subbasin	Terrain Stimulation Factor (TSF)	Broadscale Factor (BOF)	Total Adjustment Factor (TAF)
1	0.92	0.10	1.00
2	0.93	0.10	1.05
3	0.93	0.15	1.10
4	0.96	0.25	1.20
5	1.05	0.15	1.20
6	0.95	0.20	1.15
6A	1.07	0.25	1.30
7	0.90	0.15	1.05
8	1.05	0.30	1.35
9	0.91	0.15	1.05
10	1.00	0.10	1.10
11	0.99	0.10	1.10
12	1.11	0.20	1.30
13	0.97	0.05	1.00
14	1.04	0.00	1.05
15	1.05	0.00	1.05
16	1.02	0.05	1.05
17	1.09	0.10	1.20
1C	1.05	0.00	1.05
2C	1.08	0.00	1.10
3C	1.04	0.00	1.05
4C	1.05	0.00	1.05
5C	1.05	0.00	1.05

6. SPECIFIC BASIN ESTIMATES FOR PMP AND TVA PRECIPITATION

This section includes PMP and TVA precipitation estimates for 26 specific basins with areas greater than 100 mi^2 that were evaluated in the original TVA study (Schwarz and Helfert 1969). Figure 100 shows the location of the 23 basins that are in the eastern part of the basin. A description of the related topography can be found in chapter 1.

The procedures that were used to derive these estimates are those discussed in sections 5.3.1 and 5.3.2. Table 21 lists factors (broadscale orographic, terrain stimulation, and total adjustment). Note that the broadscale and total factors are rounded to the nearest 0.05. Table 22 lists the PMP and TVA precipitation estimates for the 26 basins and it should be noted that the results produced by procedures in this report differ from those in HMR No. 45. The results in table 22 supersede all previous results given for these basins. Finally, one should note that the values in table 22 are storm-areally averaged PMP and TVA precipitation values and are not areally distributed.

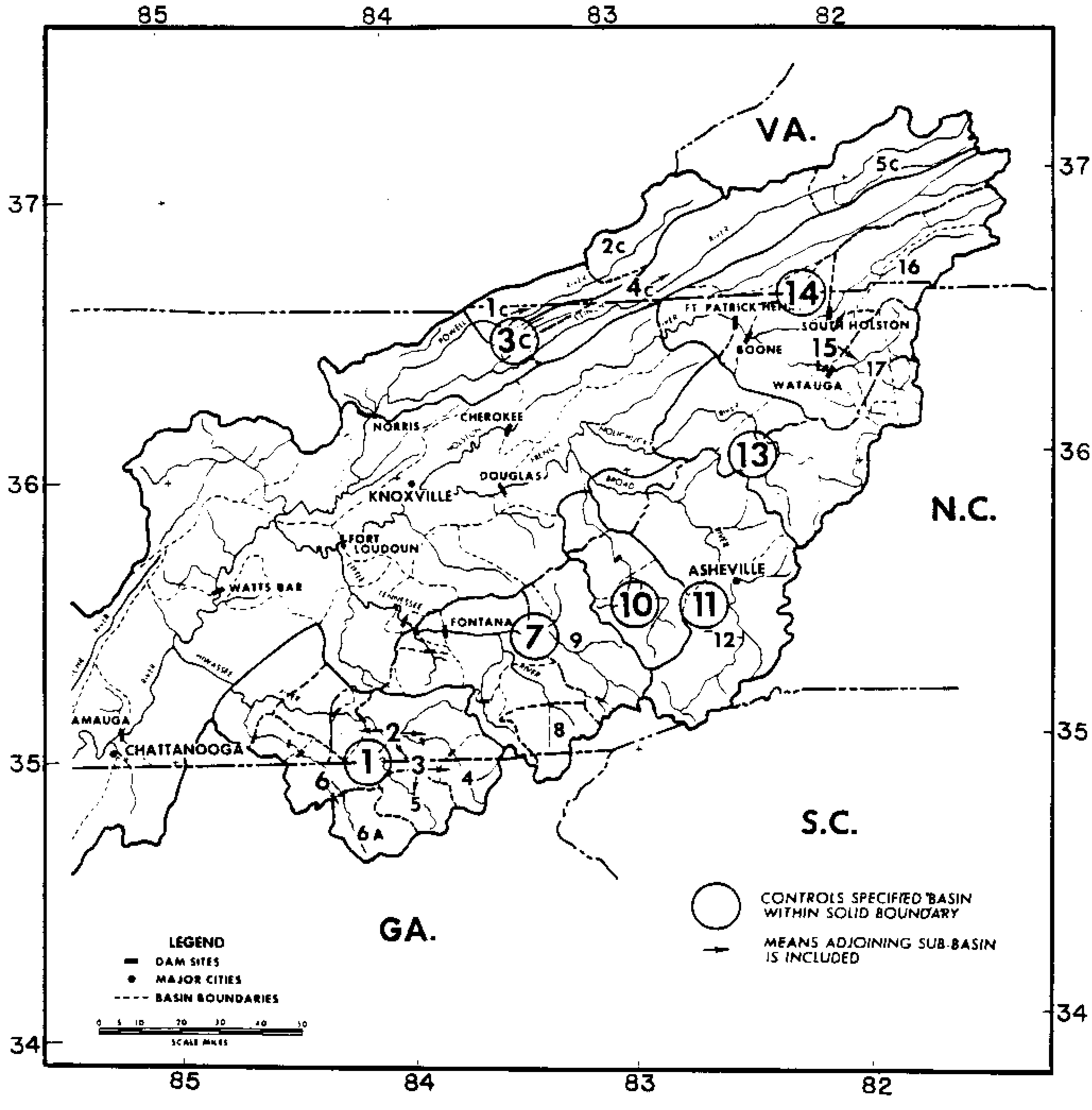

Figure 100.—Locations for subbasins given in table 21 and 22.

Table 22.--Accumulated PMP and TVA Precipitation (in.) for selected drainages*

A. Hiwassee River Drainages													
Subbasin	Precip. Type	Duration (hr.) 6	12	18	24	30	36	42	48	54	60	66	72
Hiwassee R. above Charleston, TN (Subbasin 1, fig. 100) 2,189 mi^2	PMP	11.5	14.9	17.2	18.8	20.1	21.1	21.9	22.6	23.1	23.6	24.1	24.5
	72-hr TVA	5.3	8.1	9.7	10.9	11.7	12.2	12.7	13.1	13.5	13.8	14.0	14.2
Hiwassee R. above Austral, TN (Subbasin 2, fig. 100) 1,228 mi^2	PMP	13.7	16.9	19.1	20.8	22.0	23.0	23.8	24.5	25.1	26.7	26.2	26.7
	72-hr. TVA	5.5	8.2	10.1	11.5	12.6	13.4	13.9	14.3	14.6	14.9	15.2	15.4
Hiwassee R. above Hiwassee Dam, TN (Subbasin 3, fig. 100) 968 mi^2	PMP	15.2	18.7	21.2	23.0	24.4	25.4	26.3	26.9	27.5	28.0	28.5	28.9
	72-hr. TVA	6.0	9.0	11.0	12.5	13.6	14.5	15.1	15.6	16.0	16.3	16.5	16.7
Hiwassee R. above Chatuge Dam, NC (Subbasin 4, fig. 100) 189 mi^2	PMP	22.6	26.8	29.5	31.5	32.9	34.1	35.0	35.8	36.4	37.0	37.6	38.1
	24-hr. TVA	9.0	13.7	16.2	18.1								
	72-hr. TVA	8.0	12.6	14.9	16.6	17.9	18.9	19.7	20.3	20.8	21.3	21.7	22.0
Nottely R. above Nottely Dam, GA (Subbasin 5, fig. 100) 214 mi^2	PMP	22.1	26.4	28.9	30.8	32.3	33.4	34.3	35.0	35.7	36.2	36.7	37.2
	24-hr. TVA	9.9	13.6	16.0	17.8								
	72-hr. TVA	7.8	12.2	14.6	16.4	17.6	18.6	19.4	20.0	20.5	20.9	21.2	21.5
Ocoee R. above Ocoee Ocoee Dam #1, TN (Subbasin 6, fig 100) 595 mi^2	PMP	17.9	21.7	24.2	25.9	27.3	28.4	29.3	30.1	30.0	31.5	32.1	32.7
	72-hr. TVA	7.1	10.3	12.6	14.2	15.4	16.4	17.1	17.7	18.1	18.4	18.7	18.9
Tocca R. above Blue Ridge Dam, GA (Subbasin 6A, fig. 100) 232 mi^2	PMP	24.2	28.9	31.6	33.6	35.1	36.3	37.3	38.2	39.0	39.8	40.6	41.3
	24-hr. TVA	10.4	14.5	17.2	19.3								
	72-hr. TVA	8.8	14.0	16.5	18.2	19.5	20.6	21.6	22.0	22.5	23.0	23.5	23.9

*Note: The PMP and TVA precipitation values in Table 22 represent storm averaged values while the PMP and TVA precipitation values in Table 4-1 of HMR No. 45 are basin-averaged values and therefore cannot be compared directly.

Table 22.--Accumulated PMP and TVA Precipitation (in.) for selected drainages (Continued)

Subbasin	Precip. Type	Duration (hr.) 6	12	18	24	30	36	42	48	54	60	66	72
		B. Little Tennessee River Drainages											
Little Tennessee R. Fontana Dam, NC	PMP	12.7	16.1	18.4	20.0	21.3	22.3	23.1	23.8	24.4	24.9	25.4	25.8
(Subbasin 7, fig. 100) 1,571 mi^2	72-hr. TVA	5.3	8.0	10.0	11.5	12.5	13.3	13.9	14.3	14.6	14.7	14.8	14.9
Little Tennessee R. above Franklin, NC	PMP	23.5	27.8	31.2	33.5	35.0	36.2	37.2	38.0	38.7	39.4	40.0	40.6
(Subbasin 8, fig. 100)	24-hr. TVA	10.4	14.5	17.2	19.3								
295 mi^2	72-hr. TVA	8.7	13.7	16.2	18.0	19.4	20.4	21.2	21.9	22.4	22.8	23.2	23.5
Tuckasegee R. above. Bryson City, NC	PMP	15.8	19.1	21.3	23.0	24.3	25.3	26.1	26.8	27.4	28.0	28.4	28.8
(Subbasin 9, fig. 100) 655 mi^2	72-hr. TVA	6.4	9.6	11.4	12.6	13.6	14.4	15.0	15.4	15.8	16.1	16.4	16.6
		C. Pigeon and French Broad River Drainages											
Pigeon R. above Newport, TN	PMP	16.1	19.5	21.8	23.5	24.8	25.8	26.7	27.4	28.0	28.6	29.1	29.6
(Subbasin 10, fig. 100) 666 mi^2	72-hr. TVA	6.2	9.6	11.6	13.0	14.0	14.7	15.4	15.9	16.3	16.6	16.9	17.1
French Broad R. above Newport, TN	PMP	12.5	16.0	18.3	20.0	21.3	22.3	23.1	23.8	24.4	24.9	25.4	25.8
(Subbasin 11, fig. 100) 1,858 mi^2	72-hr. TVA	5.3	8.10	10.0	11.5	12.5	13.3	13.9	14.3	14.6	14.7	14.5	14.5

Table 22.--Accumulated PMP and TVA Precipitation (in.) for selected drainages (Continued)

A. Hiwassee River Drainages

Subbasin	Precip. Type	Duration (hr.) 6	12	18	24	30	36	42	48	54	60	66	72
French Broad R. above Asheville, NC	PMP	17.9	22.4	25.2	27.2	28.7	29.9	30.9	31.7	32.4	33.0	33.6	34.2
(Subbasin 12, fig. 100) 945 mi^2	72-hr. TVA	7.2	10.7	13.1	14.9	16.2	17.2	18.0	18.5	19.0	19.4	19.6	19.8
		D. Holston and Nolichucky River Drainages											
Nolichucky R. above Nolichucky Dam, TN	PMP	10.9	14.0	16.0	17.4	18.6	19.6	20.4	21.0	21.5	22.0	22.4	22.8
(Subbasin 13, fig. 100) 1,183 mi^2	72-hr. TVA	4.7	7.1	8.8	10.0	10.9	11.6	12.0	12.4	12.7	12.9	13.1	13.2
Holston R. above Surgoinsville, TN	PMP	10.1	13.0	15.1	16.6	17.7	18.7	19.4	20.0	20.5	21.0	21.4	21.7
(Subbasin 14, fig. 100) 2,874 mi^2	72-hr. TVA	4.5	6.7	8.3	9.4	10.3	11.0	11.5	11.9	12.2	12.4	12.5	12.6
Holston R. above Fort Patrick Henry, TN	PMP	11.3	14.4	16.6	18.2	19.4	20.3	21.1	21.7	22.2	22.6	23.0	23.4
(Subbasin 15, fig. 100) 1,903 mi^2	72-hr. TVA	5.0	7.3	8.9	10.2	11.1	11.8	12.3	12.7	13.0	13.3	13.4	13.5
Holston R. above South Holston Dam, TN	PMP	14.6	17.7	20.0	21.6	22.7	23.7	24.4	25.1	25.7	26.2	26.7	27.1
(Subbasin 16, fig. 100) 703 mi^2	72-hr. TVA	5.6	8.6	10.3	11.6	12.4	12.9	13.4	13.8	14.2	14.6	14.8	15.0

Table 22.--Accumulated PMP and TVA Precipitation (in.) for selected drainages (Continued)

Subbasin	Precip. Type	Duration (hr.) 6	12	18	24	30	36	42	48	54	60	66	72
Watauga R. above Watauga Dam, TN (Subbasin 17, fig. 100) 468 mi^2	PMP	17.9	21.8	24.2	26.0	27.2	28.3	29.1	29.8	30.5	31.2	31.7	32.2
	72-hr. TVA	6.6	10.1	12.1	13.7	14.5	15.2	15.8	16.3	16.8	17.2	17.5	17.7
Powell R. above Arthur, TN (Subbasin 1C, fig. 100) 684 mi^2	PMP	14.4	17.4	19.6	21.2	22.3	23.2	23.9	24.5	25.1	25.6	26.1	26.6
	72-hr. TVA	5.5	8.4	10.1	11.3	12.1	12.7	13.2	13.6	13.9	14.2	14.5	14.7
Powell R. above Jonesville, TN (Subbasin 2C, fig. 100) 319 mi^2	PMP	16.6	19.8	22.0	23.8	24.8	25.7	26.4	27.0	27.6	28.2	28.7	29.2
	72-hr. TVA	6.0	9.2	11.0	12.4	13.5	13.9	14.3	14.7	15.1	15.5	15.9	16.1

Table 22.--Accumulated PMP and TVA Precipitation (in.) for selected drainages (Continued)

E. Clinch River Drainages

Subbasin	Precip. Type	Duration (hr.) 6	12	18	24	30	36	42	48	54	60	66	72
Clinch R. above Norris Dam, TN	PMP	10.0	12.8	15.0	16.6	17.5	18.3	19.0	19.6	20.1	20.6	21.1	21.6
(Subbasin 3C, fig. 100) 2,912 mi^2	72-hr. TVA	4.4	6.8	8.2	9.2	9.8	10.2	10.6	11.0	11.3	11.6	11.8	11.9
Clinch R. above Tazewell, TN	PMP	11.9	14.9	17.1	18.7	19.5	20.3	21.1	21.8	22.4	23.0	23.4	23.8
(Subbasin 4C, fig. 100) 1,474 mi^2	72-hr. TVA	4.9	7.5	9.1	10.2	10.9	11.4	11.8	12.2	12.5	12.8	13.0	13.2
Clinch R. above Cleveland, TN	PMP	14.7	17.6	19.6	21.3	22.4	23.2	24.0	24.6	25.2	25:7	26.1	26.5
(Subbasin 5C, fig. 100) 528 mi^2	72-hr. TVA	5.5	8.4	10.1	11.3	12.1	12.7	13.1	13.5	13.9	14.3	14.5	14.7
F. Western Basins													
Duck R. Drainage	PMP	12.7	15.8	18.1	20.1	21.3	22.3	23.2	23.8	24.3	24.8	25.2	25.6
1,208 mi^2	72-hr. TVA	6.8	8.5	9.7	10.8	11.4	12.0	12.5	12.8	13.0	13.2	13.4	13.6
Emory R. Drainage	PMP	14.7	17.5	19.5	21.2	22.7	23.9	24.6	25.3	25.9	26.4	26.9	27.5
798 mi^2	72-hr. TVA	5.2	8.6	10.2	11.3	12.0	12.5	12.9	13.3	13.7	14.0	14.3	14.6
Obed R. Drainage	PMP	16.4	19.5	22.0	23.7	24.8	25.8	26.6	27.2	27.8	28.4	28.9	29.4
518 mi^2	72-hr. TVA	5.6	8.8	10.9	12.1	12.9	13.5	13.9	14.3	14.7	15.0	15.3	15.6

7. ANTECEDENT RAINFALL

7.1. Introduction

Antecedent rains are important in determining the size of a flood that occurs on a particular basin. HMR No. 41 (Schwarz 1965) develops antecedent rainfall criteria for large-size basins above Chattanooga. In this report the concern is with antecedent rainfall both for small basins less than 100 mi^2 and for intermediate-size basins ranging from 100 to 3,000 mi^2. For small basins, antecedent rainfall is applied to maximum 24-hr rains, while for the intermediate size basins, conditions prior to 3-day maximum rains are required.

The antecedent rainfall amounts at the TVA precipitation level are intended to be conditions that normally occur prior to significant rains and are selected with the intent that their use does not change the probability of the total event. Thus, if a 3-day antecedent rain is added to a 3-day TVA rain with 3 intervening rainless days, the intention is that the probability of the 9-day event is about the same as that of the 3-day TVA precipitation event. When adopting antecedent conditions for the PMP storm, the condition of equal probability is relaxed.

The study of antecedent rainfall is broken into two separate studies: (1) rainfall antecedent to 24-hr intense small-basin PMP and TVA precipitation, and (2) rainfall antecedent to 3-day PMP and TVA precipitation for larger basins.

Antecedent criteria presented in this chapter are intended to cover all basins encountered in application of the generalized procedures of chapter 5. For simplicity of application, and to avoid compounding of probabilities, the antecedent rainfall should be uniformly distributed over the basin.

7.2 Conditions Anteceding Maximum 24-hr Rainfall

7.2.1 Data Used in the Analyses

From the months of June through October for the period 1937-1965, daily rainfalls of over 5 and 7 in. were selected from over 600 stations in the Tennessee River watershed. Of the 168 cases exceeding 5 in., June had the lowest number of cases with 17 and September the highest with 45. The rains during the 5 days prior to the day of maximum rainfall were summarized both for cases exceeding 5 in. and for the smaller number of cases exceeding 7 in.

Another set of data consisted of high daily rains within two exceptionally rainy months in the Tennessee River watershed, August 1901 and July 1916. In these two months all stations with daily rainfall of 4 in. or more were summarized, and the rainfall for each of the 5-antecedent days tabulated.

A third set of data are the rains antecedent to extremely intense 24-hr summer rainfalls in and near the Tennessee River watershed. These are perhaps the best indicators for setting rains antecedent to maximum 24-hr values. One problem, however, is that the most intense rains usually are reports from bucket surveys and are, therefore, at locations where the rains for previous days are not reported. However, for 10 such rains the average antecedent rainfall could be estimated from nearby regularly reporting stations.

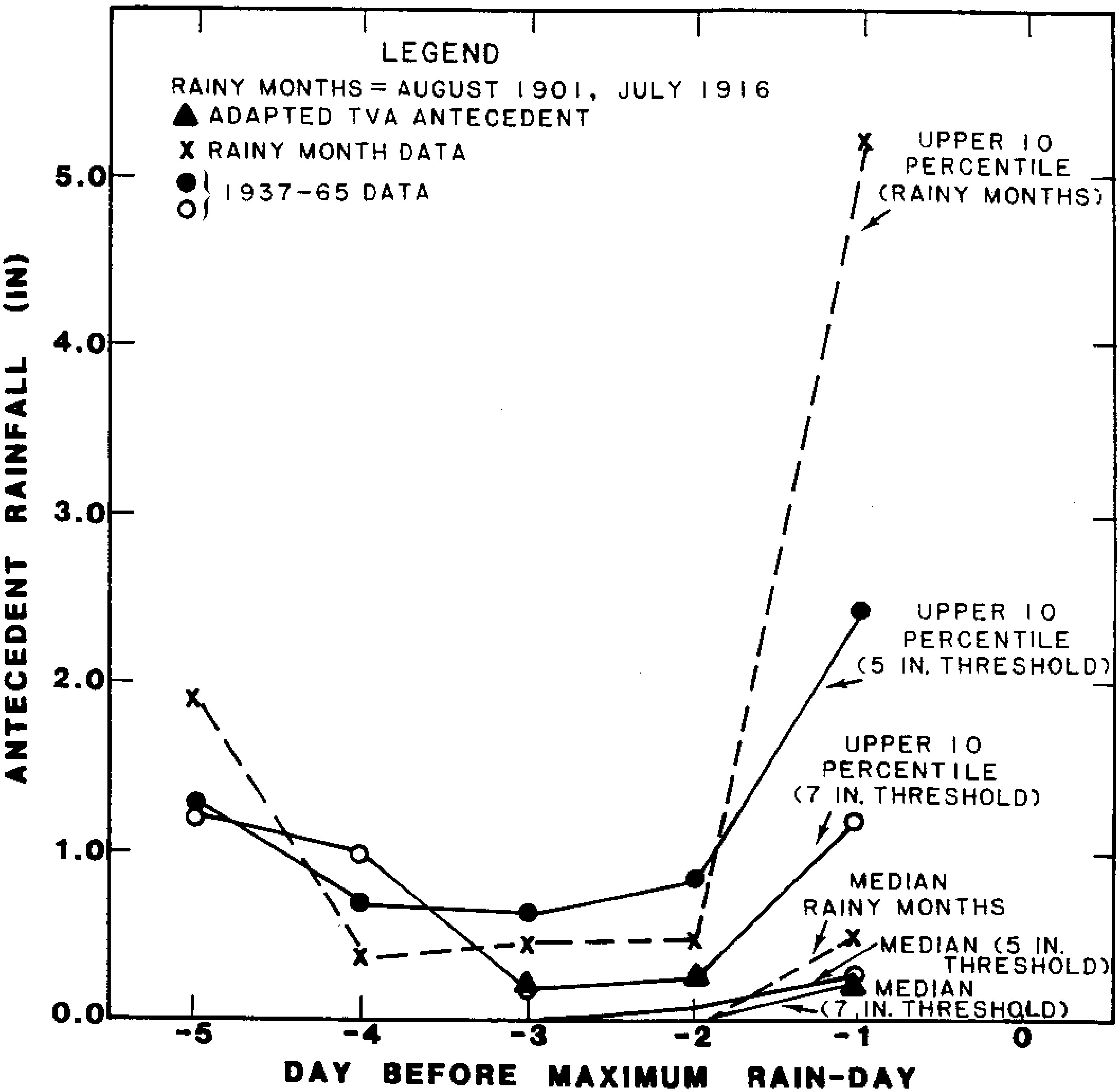

Figure 101.—Antecedent rainfall of moderately heavy rain situations from 1937-1965.

In addition to the 3 sets of data above, frequency analyses were made of daily rains at 4 stations for the months of May through September using 20 yr of data.

7.2.2 Analyses of Antecedent Rainfall Preceding Maximum 24-hr Rainfall

Of the 10 intense rains in the Tennessee River watershed, rains for which antecedent conditions could be evaluated, most were preceded by 2 to 3 days of showery conditions. This appeared to be part of the process of building up to the extreme rain. Antecedent rainfall did not appear to favor significantly any 1 of the 3 days more than the other 2. The average of the daily antecedent rainfall was 0.26 in. on each of the 3 days.

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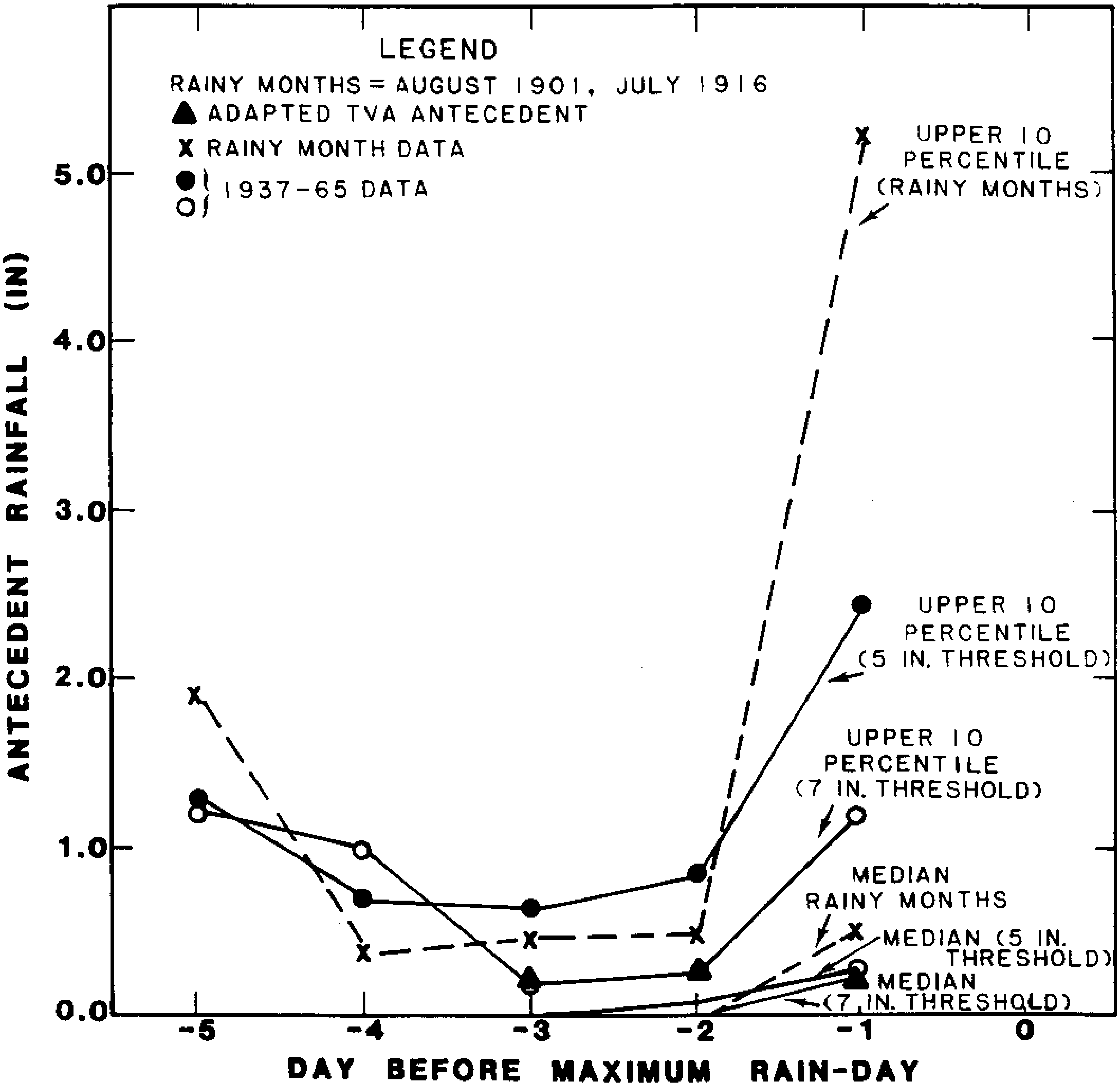

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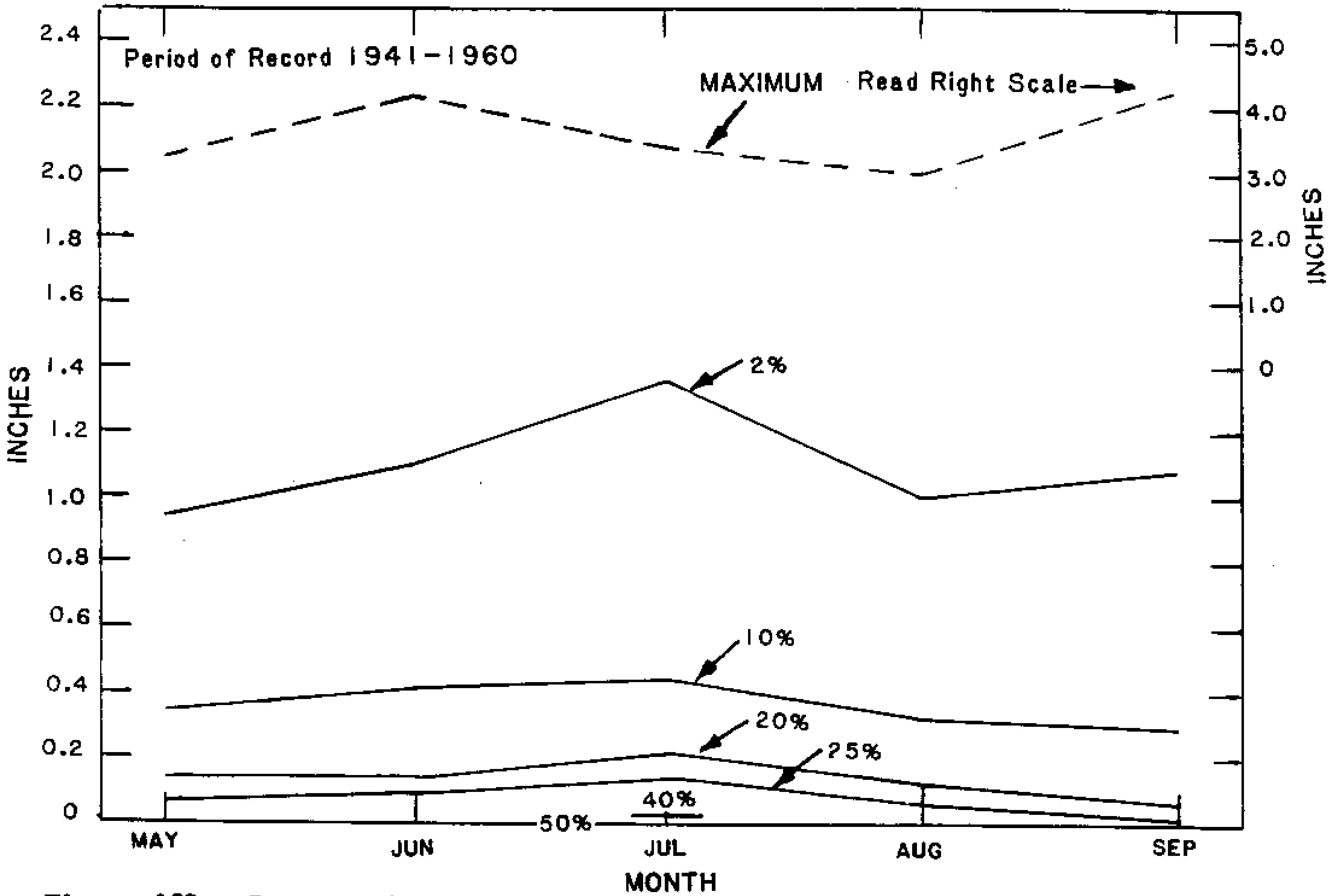

Figure 102.--Percent chance of daily rainfall at Asheville, NC.

Figure 101 shows the results of analyses of the moderately heavy rain situations from the 1937-1965 survey and the two rainy months. Median and upper 10-percentile values resulting from a statistical analysis of each are given. At the median level of the 7-in. threshold data, the amount of first-day antecedent rainfall did not differ significantly from that of the 5-in. threshold data (0.25 in.). However, for the rarer event (upper 10-percentile) the first-day antecedent rainfall decreased considerably for the 7-in. threshold compared to the 5-in.

The 53 cases of daily rainfall greater than or equal to 4 in. in August 1901 and July 1916 are referred to as "rainy months" data in figure 101. These have antecedent rains comparable to the previous set except at the upper 10-percentile point on the first antecedent day. The median rainfall 1 day prior to large daily amounts is 0.25 in. (fig. 101). This comparison shows that there is some association of rain one day with the next.

The question of dependence of rainfall events can be resolved in part by comparing median rainfall for all days with the median on days prior to large storms. A frequency analysis of a 20-yr daily rainfall record (1941-60) was made at four stations for the months of May through September. Figures 102 through 104 summarize expected daily rainfalls at 3 of the stations, Asheville, Chattanooga, and Memphis for various probability levels. The maximum for the 1941-1960 period is also shown. There is a 50 percent probability of no rain for all 3 stations. The fourth station at Tray Mt. showed questionable data for July and plotted data were not shown.

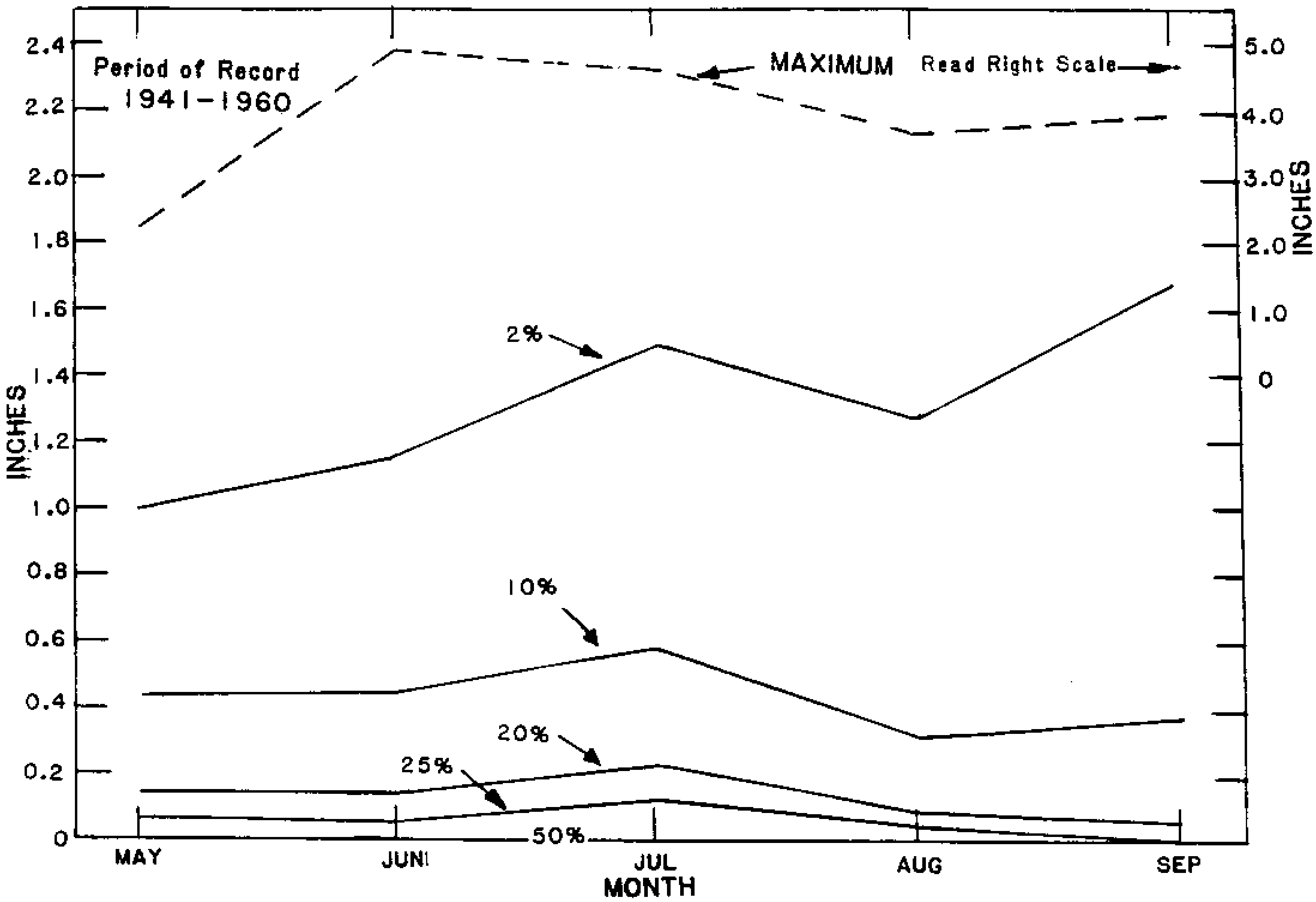

Figure 103.--Percent chance of daily rainfall at Chattanooga, TN.

The interdependence is strong at the 10-percentile level. Table 23 lists the upper 10-percentile values from all daily rainfalls at 4 stations. The May through September average of the upper 10-percentile is 0.45 in., significantly different from the 10-percentile first-day antecedent value of 1.2 and 2.5 in. for the 7- and 5-in. thresholds, respectively.

The analysis discussed above supports the conclusion that rainfall prior to the PMP and TVA 24-hr storm will tend to exceed the average. One reason for this, physically, is persistence of a broadscale synoptic situation favorable for heavy rains. This results in the influx of high moisture into the area so that some shower activity is likely to precede a heavy rain situation.

<u>Adopted values antecedent to maximum 24-hr rain</u>

Antecedent rainfall of 0.25 in. for each of 2-antecedent days preceding the 24-hr TVA storm is recommended for application to all small basin estimates. Such magnitudes are supported both by the conditions preceding extreme summer short-duration rainfalls in the Tennessee River watershed, and the median antecedent conditions preceding the greater number of less extreme, but still large rainfall amounts.

For PMP storms where there is less concern about making the event less probable, more extreme antecedent possibilities are appropriate. An assessment of the highest observed storm rainfall amounts for durations of 48 and 72 hr provides guidance in selecting antecedent rainfall to go with 24-hr PMP over small basins. HMR No. 51 (Schreiner and Riedel 1978) provides such guidance.

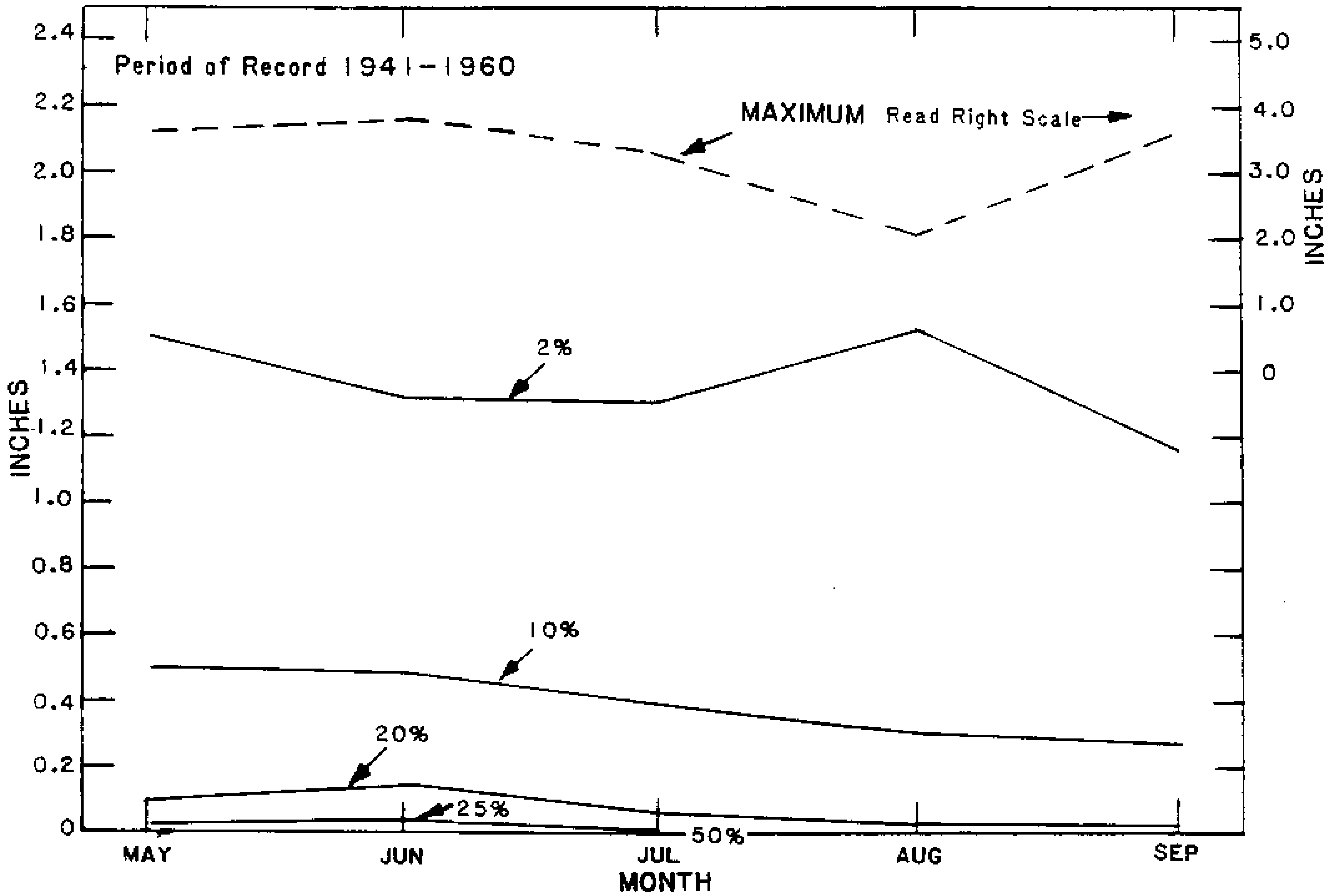

Figure 104.—Percent chance of daily rainfall at Memphis, TN.

Table 23.— Upper 10-percentile of average daily rainfall (in.) (1941-1960)

Station	May	June	July	August	September
Asheville	.34	.41	.44	.32	.29
Chattanooga	.43	.44	.57	.30	.36
Memphis	.50	.49	.39	.30	.27
Tray Mt.	.72	.51	.90	.54	.64
Mean	.50	.46	.56	.36	.39

May-September mean 0.45

Use of the data in HMR No. 51 at 72 hr, combined with a 2 to 1 apportioning of antecedent vs. subsequent (following the precedent of HMR No. 41) results in an adopted 10-percent increment for the first day adjacent to the 24-hr PMP and 2 percent for the second adjacent day. These incremental percentages are to be applied to the 24-hr PMP for the range of basin sizes of 10 to 100 mi^2.

For basin sizes of 1 to 9 mi^2 and a duration of 72 hr, it is recommended that figures 52, 54, and 55 be used to obtain a basin 72 hr 1- to 9-mi^2 PMP. The 72-hr PMP curve in figure 52 needs to be extrapolated from 100 to 1 mi^2. Given the 72-hr PMP for the basin, the incremental percentages of 10 percent increment for the first day adjacent to the 24-hr PMP and 2 percent for the second adjacent day are used for antecedent PMP.

7.3 Conditions Anteceding Maximum 3-Day Rainfall

7.3.1 Introduction

For basins with drainage areas of greater than one hundred to several thousand square miles, sequences of recurring rainfall become increasingly important. With the broadscale meteorological controls remaining relatively fixed, storms may readily repeat over approximately the same area. For very large basins, the January 1937 rainfall in the Tennessee River and Ohio River watersheds is an outstanding example of such an event (Schwarz 1961). For more moderate-size basins in the mountainous eastern portion of the Tennessee River watershed (Tennessee Valley Authority 1961), the repeating, hurricane-associated rainfall in July 1916 provides an excellent example.

The intent in this section is to develop antecedent rainfall criteria applicable to maximum 3-day rains for the PMP level. Two problems are addressed initially. First is the appropriate length of the dry interval between major storms. Second is the magnitude of the antecedent storm with a minimum dry interval. Section 7.3.2 establishes a minimum dry interval of 3 days through examination of antecedent rainfall associated with major U.S. storms. In section 7.3.3., two general approaches are used as guidance in judging what the magnitude should be: (1) statistical guidance from station data, and (2) rainfall antecedent to major U.S. storms. After a minimum dry interval of 3 days was established, a third question was considered. Would the antecedent rain increase significantly if 5 dry days were allowed rather than 3?

7.3.2 Interval Between the Antecedent Storm and the Primary or Main Storm

Previous investigations in HMR No. 35 (Myers 1959), HMR No. 38 (Schwarz 1961), and HMR No. 41 (Schwarz 1965) were directed toward establishing critical meteorological sequences of storms. Figure 105 is an example of the daily changing synoptic (surface weather) transition from one major storm to the second. These hypothetical transition sequences led to the conclusion that 3 days is the minimum interval between major storms for large river basins away from the coast. Many sequences of storms were examined in these studies. Different types of transition from the weather situation at the end of the first storm to that at the beginning of the second storm were examined. It was found that generally 3 days was the minimum time interval required for a reasonable transition from the weather situation at the end of one storm to that at the beginning of the next.

Major rain storms require a storm influx of moisture from a southerly direction, particularly for regions away from coastal areas. The rains are then terminated by colder, drier air flowing from the north or northeast continental regions. The more intense the storm, the greater the inflow of drier air pushing behind the rain producing system and the farther the drier air spreads over the region and across the moisture source region, in this case southward across the Gulf of Mexico. For the gradients and wind flows to reverse themselves and once again provide significant moisture transport to larger basins away from the Gulf of Mexico requires a minimum period of approximately 3 days. As the magnitude of the first storm in the sequence increases, the time interval required to reestablish moisture and stability conditions necessary for a second major storm either increases or the second storm will be reduced in potential. For major

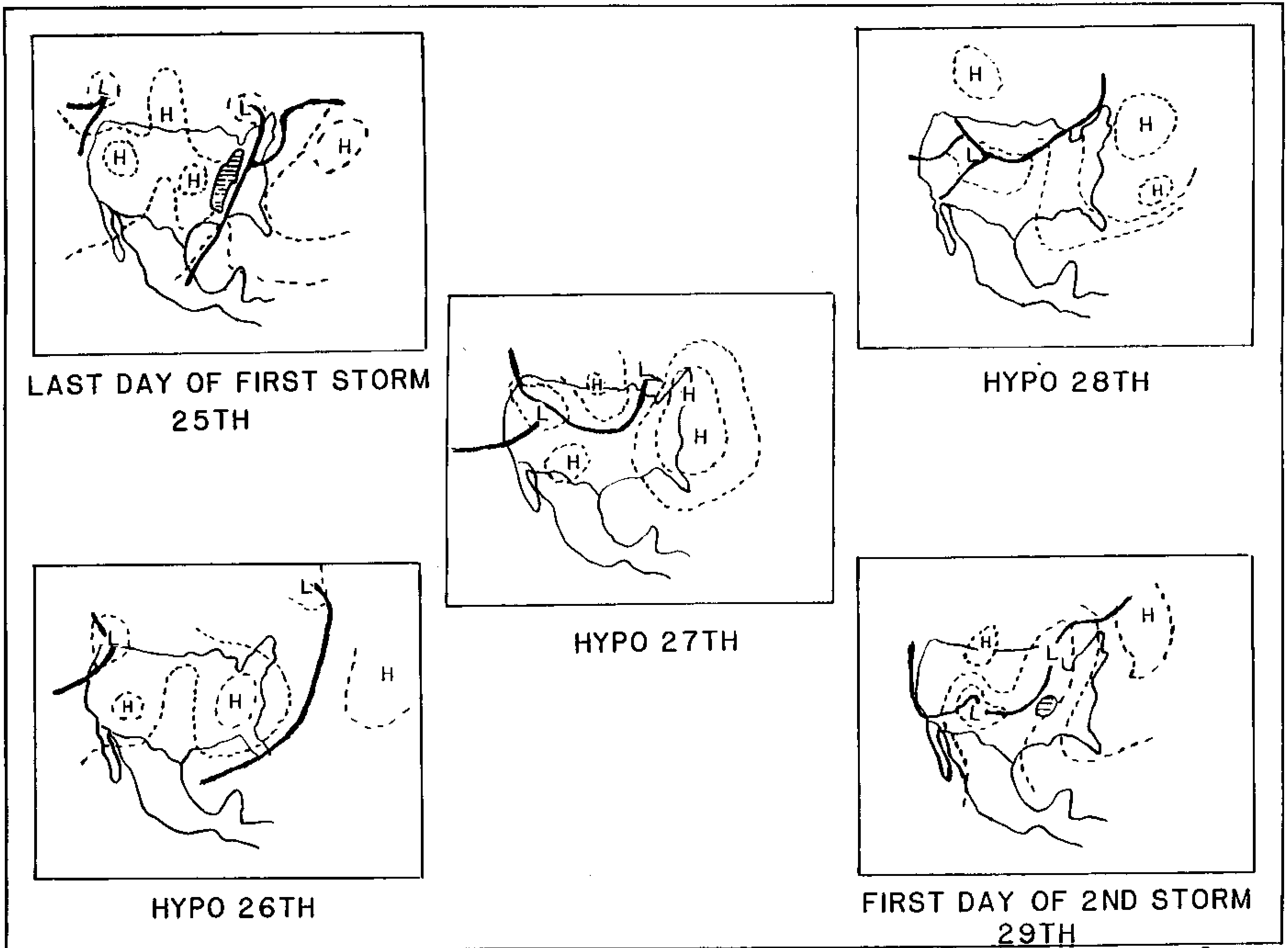

Figure 105.--Hypothetical transition from one major storm event to a second major storm event. Sequence illustrates minimum time interval.

storms in the Tennessee Valley area, this moisture must be persistently transported from quite low latitudes in the Gulf of Mexico. A shorter time interval between major storms would require unrealistic wind speeds, directions of movement, and transformations of highs and lows. Intervals longer than 3 days allow the cold dry continental air to remain over the basin for longer periods before the moisture laden air flow from the south is reestablished.

A 3-day rainless interval preceding both the PMP and TVA maximum 3-day rain has been adopted in this study. The relative rarity of the total rainfall event for PMP vs. TVA precipitation is handled by changing the magnitude of the antecedent rainfall rather than using a varying rainless interval.

7.3.3 Magnitude of Antecedent Storm 3 Days Prior, as Percent of Main Storm

A probable maximum storm is an extremely rare event. It has not been equaled by any historic event. In only a few cases has any storm come close to PMP and then only for a few durations and area sizes. Estimates of rainfall antecedent to PMP must be determined from storms of lesser magnitude. Several approaches were used to determine the appropriate magnitude for the Tennessee Valley.

7.3.3.1 Guidance From Station Rainfall Events. Information about antecedent storms for areas in the smaller end of the size range of interest can be gained from investigation of point or station rainfall data. The data are the rainfall observations taken at the many stations for which the National Weather Service publishes daily rainfall amounts.

Four different procedures were used in developing guidance from station rainfall values; 1) ratios of 9- to 3-day 100-yr rainfall; 2) average ratios of 6-day rain adjacent to or surrounding the maximum annual 3-day rainfalls for 250 stations in eastern Tennessee and western North Carolina; 3) average ratios between the 6-day adjacent rain and the maximum 3-day value within a 9-day storm for rains greater than 4.5 in. in 9 days for four stations, and 4) ratios between the 6-day adjacent rain and 3-day rains greater than 7 in. from 4,000 yr of stochastically generated rainfall values at Bristol, TN.

In the station rainfall studies, two approaches were used. In one, the maximum annual 3-day amount was selected and the largest 6-day amount adjacent to the maximum 3-day amount was determined. The 6 days could be either completely before or after the 3-day period, or it could be partly before or after (fig. 106). In the other, the maximum annual 9-day amount was selected and the maximum 3-day period within the total storm determined.

7.3.3.1.1 Ratio of 9- to 3-day 100-yr rainfall. Rainfall-frequency values for the 100-yr recurrence interval for 2- to 10-day periods are readily available (Miller 1964). Ratios of 9-day 100-yr to 3-day 100-yr values were determined for a grid of points in and surrounding the Tennessee Valley. Isopleths drawn to this grid point data are shown in figure 107. The average ratio for the Valley is slightly over 1.30.

These ratios can only be used as guidance to ratios applicable to the main storm plus antecedent storm sequence and cannot be applied directly. They are slightly higher than would be expected in that sequence for the following reasons:

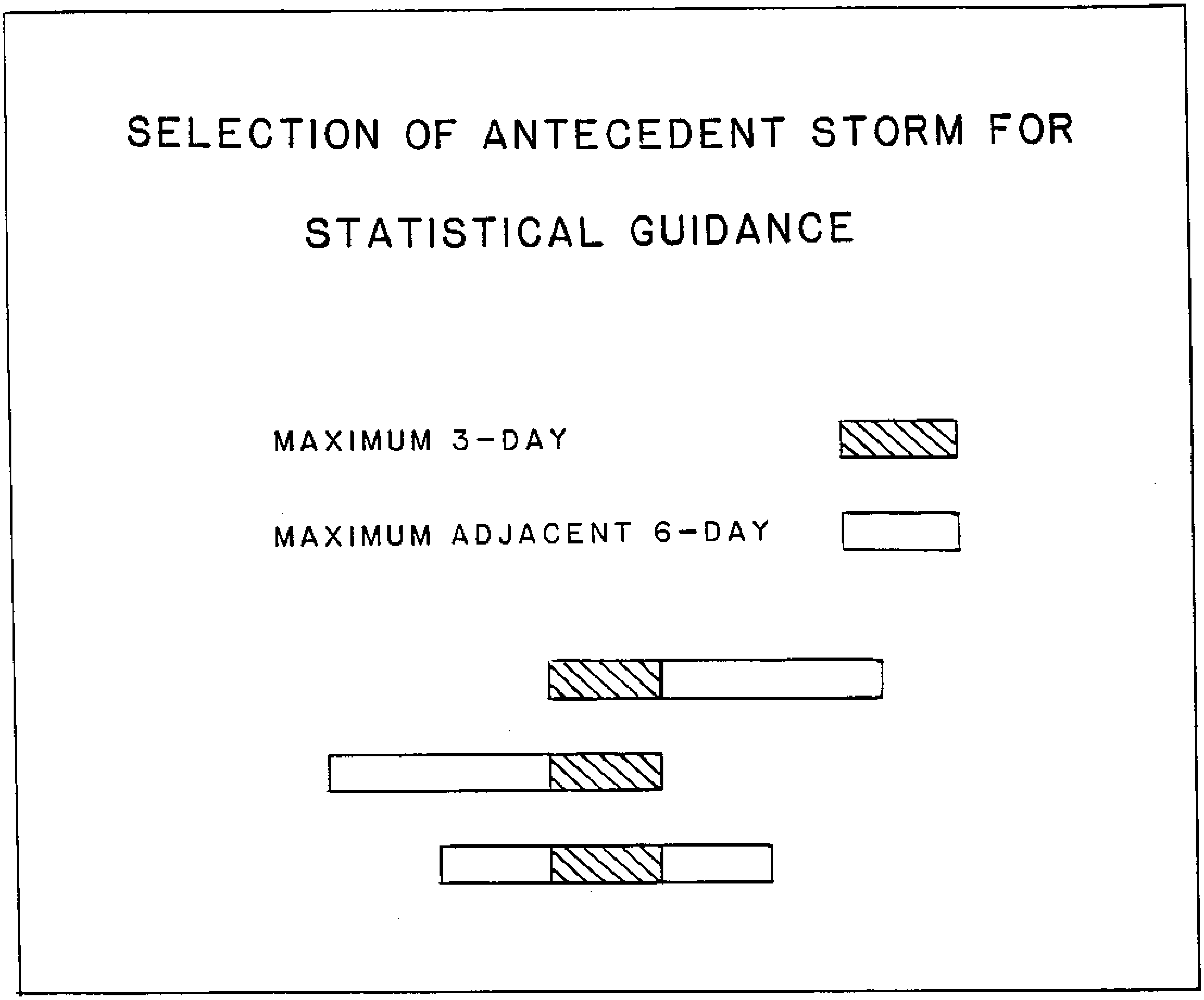

Figure 106.--Illustration of method for selecting maximum 6-day rainfall associated with maximum 3-day amounts. Rain may occur in any one or all of the 9-day period. The 6-day event may be any combination of days before or after providing only that the 9 days are consecutive.

1. The ratio procedure assumes the 3-day 100-yr rain occurs within the 9-day 100-yr rain, while each of the values was obtained from independent data sets. In some cases, individual maximum 3-day and 9-day values are from situations not meteorologically compatible; e.g., the 3-day amount may be from a tropical storm and the 9-day amount from a series of extratropical low pressure systems occurring in spring or winter. Studies for the Ohio River Valley (Miller and Frederick 1972) and the Arkansas-Canadian River Valleys (Frederick 1973) indicate that the 3-day 100-yr rain generally does not occur within the 9-day 100-yr rain.

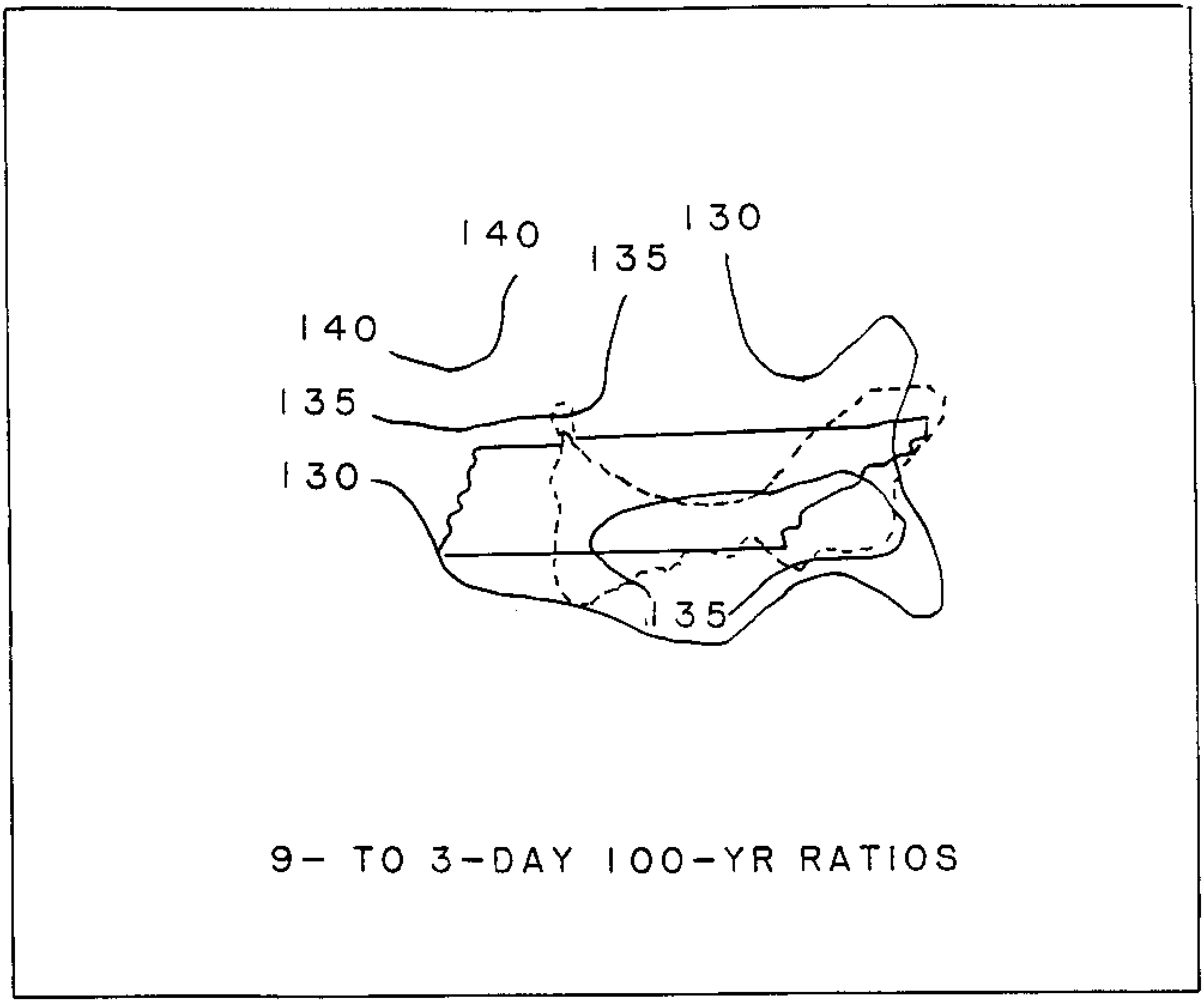

Figure 107.--Ratio of 9-day 100-yr to 3-day 100-yr precipitation values for Tennessee Valley.

2. The difference between 9-day and 3-day values (generally 30-38 percent of the 3-day) can occur in more than 3 of the 6 remaining days.

7.3.3.1.2 6-day rain adjacent to maximum annual 3-day rain. For 250 stations in Tennessee east of 86°W and in North Carolina west of 80°W, 25 yr of data ending in 1973 were available on magnetic tape. For these stations, the maximum annual 3-day rain and the maximum 9-day value including the 3-day maximum were found for each year of record. From this, the 6-day rain adjacent to or surrounding the maximum 3-day rain was determined. The data were grouped according to the magnitude of the 3-day value. Three intervals were selected: Less than 4 in., 4 to 6 in., and greater than 6 in. Figure 108 shows average adjacent rainfall for the 6 days in terms of a percent of the 3-day rainfall. It is evident from this plot, as the magnitude of the 3-day rain increases, the average adjacent storm as a percent of the major storm decreases. For the smallest 3-day rainfall amounts, 0 to 4 in., the average adjacent rain is about 27 percent. When the 3-day rains are in excess of 6 in., the adjacent rain on the average is less than 15 percent of the maximum 3-day value. Maximum observed station rainfalls are less than PMP magnitude, but extrapolation to that magnitude would give lower

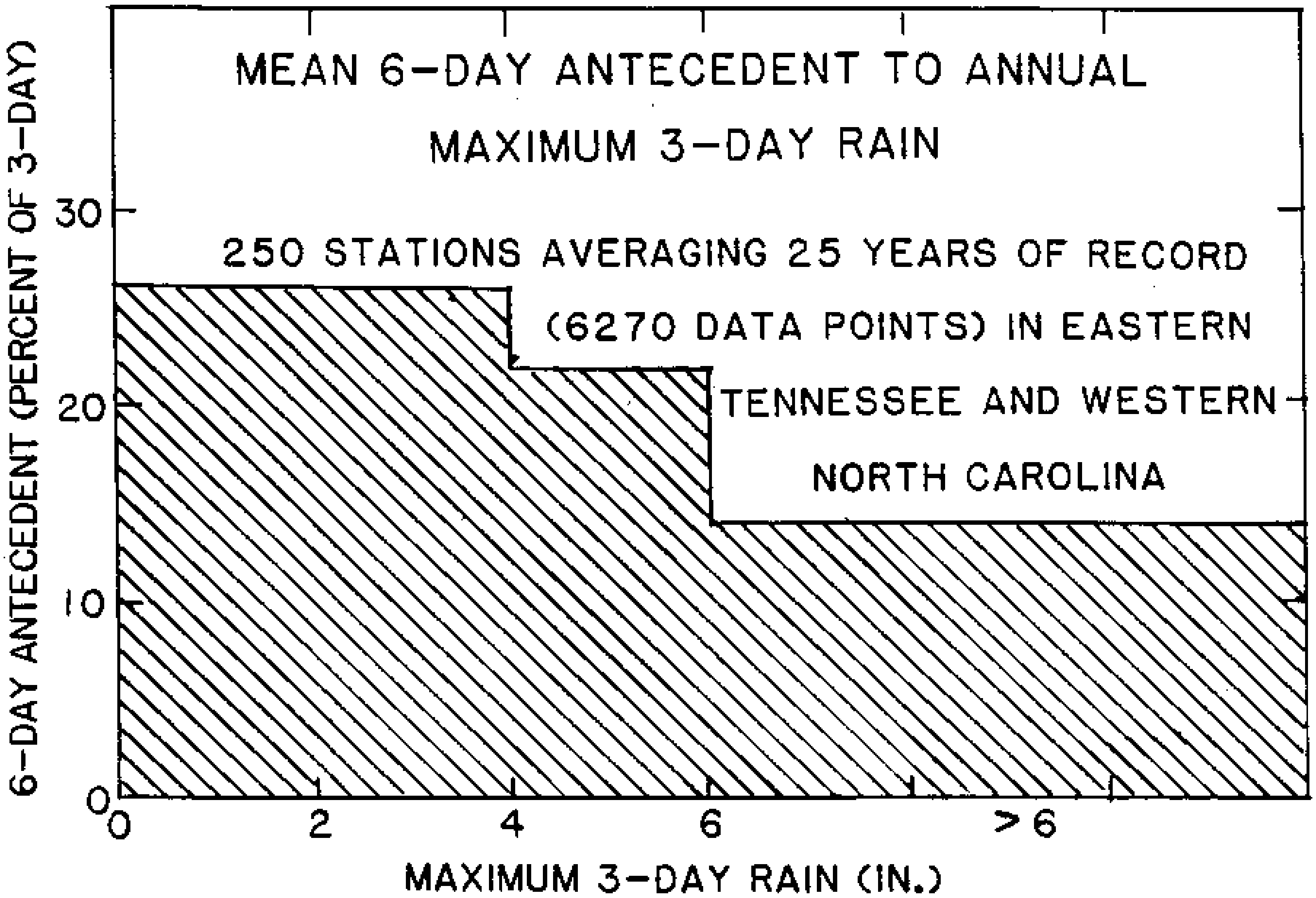

Figure 108.--Average ratio of 6-day rain antecedent to maximum 3-day rains for 250 stations in eastern Tennessee and western North Carolina.

percentages of between 10 to 15 percent. There are several reasons this guidance from maximum 3-day rain and adjacent 6-day rain shows decreasing percentages of antecedent rain in relation to the primary storm.

1. Meteorologically, the trend of decreasing adjacent rain with increasing magnitude of the 3-day storm is realistic. The more intense the first storm, the more unlikely it is to have a following intense storm in a short period of time. Now having set the 3-day PMP (between 33 and 44 in. for stations in this region) it follows, it is more and more unlikely to realize a large antecedent rain as the magnitude of the primary storm increases.

2. The adjacent rain is made up of the sum of the rain for 6 days. These 6-days can all occur (1) before the 3-day maximum rain, (2) after it, or (3) encompass the 3-day maximum rain; e.g., 2 days before it and 4 days after it. If the data selected were restricted to 6 consecutive days, either before or after, some of the resulting antecedent rainfalls would be less.

3. The adjacent rain determined does not conform to the sequence of 3 dry days between the 3-day antecedent storm and the 3-day main storm. We have summed the rain for a 6-day period (or 2 shorter periods broken by the maximum 3 days). Were the data restricted to sequences with 3 dry days, or even used as only

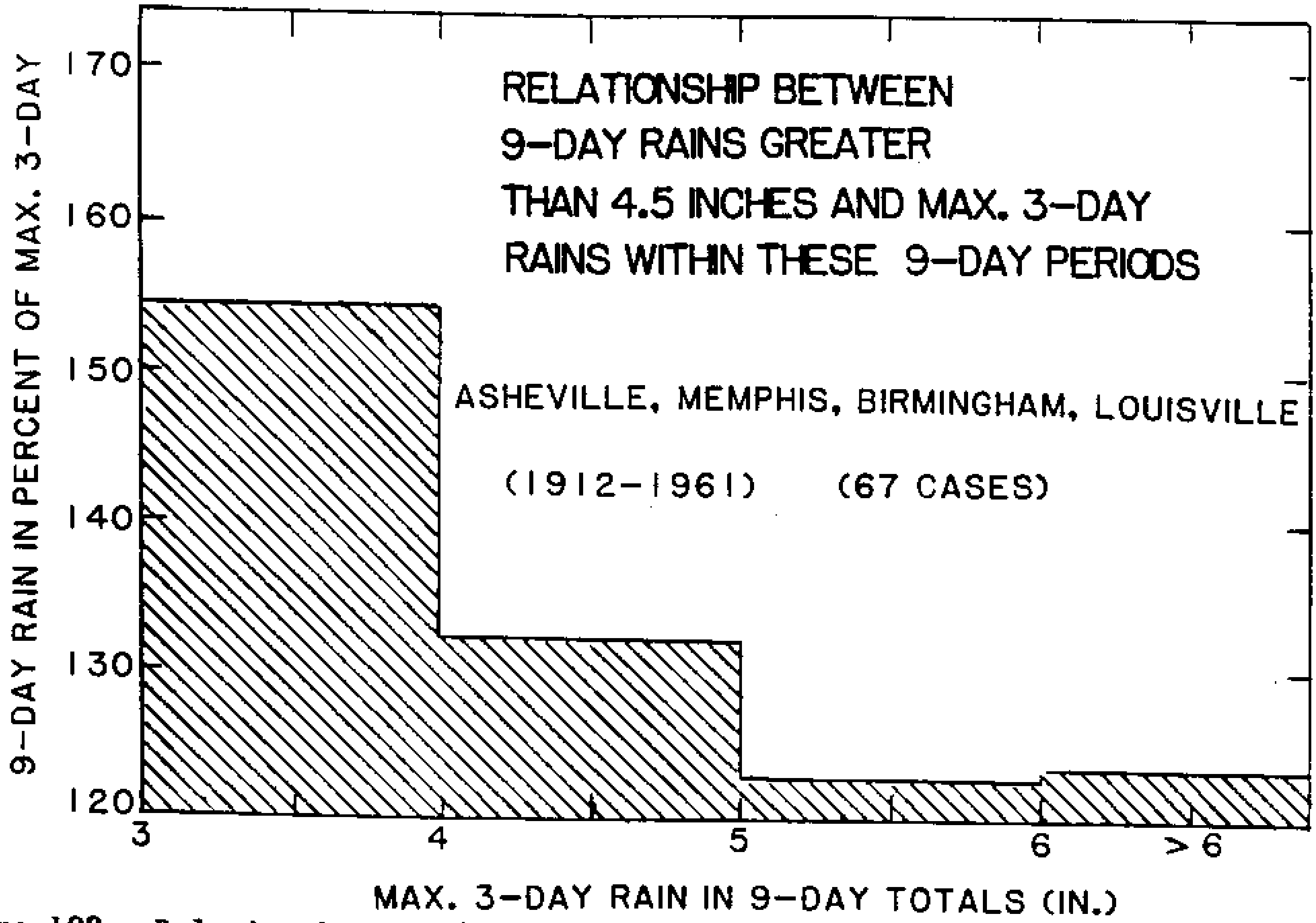

Figure 109.--Relation between 9-day rains, greater than 4.5 in. and maximum 3-day rains within those 9-day periods. Data are for 50-yr period 1912-1961 for Asheville, NC, Memphis, TN, Birmingham, AL and Louisville, KY.

the rain over a 3-day period, with a 3-day gap before or after the 3-day maximum value, the resulting antecedent would be much less. The adjacent rain could just as well have occurred in 3 days, with a 3-day dry interval.

<u>7.3.3.1.3 Station 9-day rains greater than 4.5 in.</u> Maximum 9-day warm season June through October rains, for the period 1912-61 at Asheville, Memphis, Birmingham and Louisville provided additional information to help evaluate antecedent rains. Memphis, TN, and Asheville, NC, are representative of two different topographic settings within the Tennessee Basin. The mountainous east is represented by Asheville and the less rugged western portion of the Tennessee drainage by Memphis, TN. Birmingham, AL and Louisville, KY, provide useful information south and north of the basin, respectively.

During this period, 67 cases of 9-day rains in excess of 4.5 in. were found. The data were summarized by magnitude of the maximum 3-day rain. This relation is illustrated in figure 109 and shows a decrease of the adjoining rain as the magnitude of the maximum 3-day rain increases. This is the same trend that is shown in the data for the 250 stations in eastern Tennessee and western North Carolina. The maximum 3-day rainfall was 12.27 in. The 9- to 3-day ratio for this storm was 1.24. Extrapolation of this or the average ratios to the PMP magnitude would give lower values, slightly less than 20 percent. The 1-percent increase for the 9 cases with 3-day rains greater than 6 in. is not statistically significant.

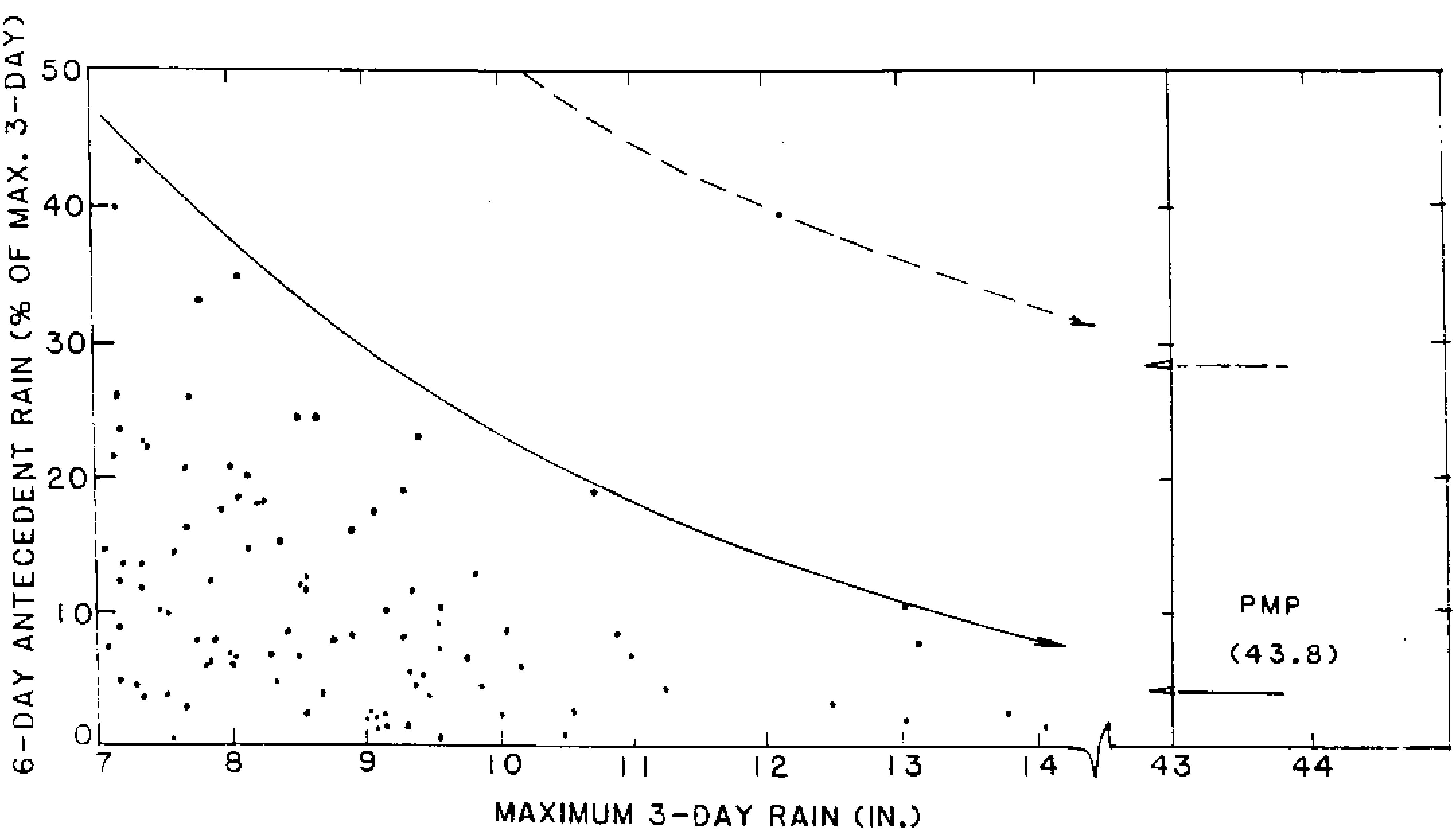

Figure 110.--Relation between statistically generated maximum 3-day rains and 6-day antecedent rainfall based on Bristol, TN data. First-order Markov chain, Kappa 3 distribution and retaining proportion of days above various thresholds among primary criteria for generating statistical series.

The same maximizations are present in this data set as in the previous ones. The adjoining rainfall may come from 2 storms and the 6-day amount is assumed to occur in 3 days. These two factors bias the results toward a higher percentage than can be expected in a large primary storm plus antecedent storm sequence.

__7.3.3.1.4 Statistically generated rainfall data.__ Among the newer techniques of rainfall analysis is the generation of a long series of daily rainfalls that preserve the statistical properties of the initial data sample. This has been done for Bristol, TN to gain additional insight into the question of antecedent precipitation. The basic period of record for the daily rains is for the 25 yr between 1949 and 1973. Very briefly, the technique used a first-order Markov chain to describe the variations between rain days and no rain days. Then rainfall amounts were generated by the Kappa 3 distribution. In all rainfall generation techniques some upper bound is necessary. In this study, an upper bound equivalent to the PMP at this location was used. The calibration scheme applied also preserved the observed mean daily rainfall and the proportion of days with rain exceeding certain threshold values. The maximum daily rainfall generated was a little less than 12 in. or about 4 times the maximum observed. The maximum 3-day rain generated was a little over 14 in. or about 3 times the maximum observed.

For this particular application, forty 100-yr periods of daily rainfalls were generated. From each 100-yr segment, all 3-day rains in excess of 7 in. were selected and the maximum 9-day rain was determined which included the 3-day period. The results of this study are shown in figure 110. A trend line (solid line) is shown that envelops most of the data. This shows a decrease in

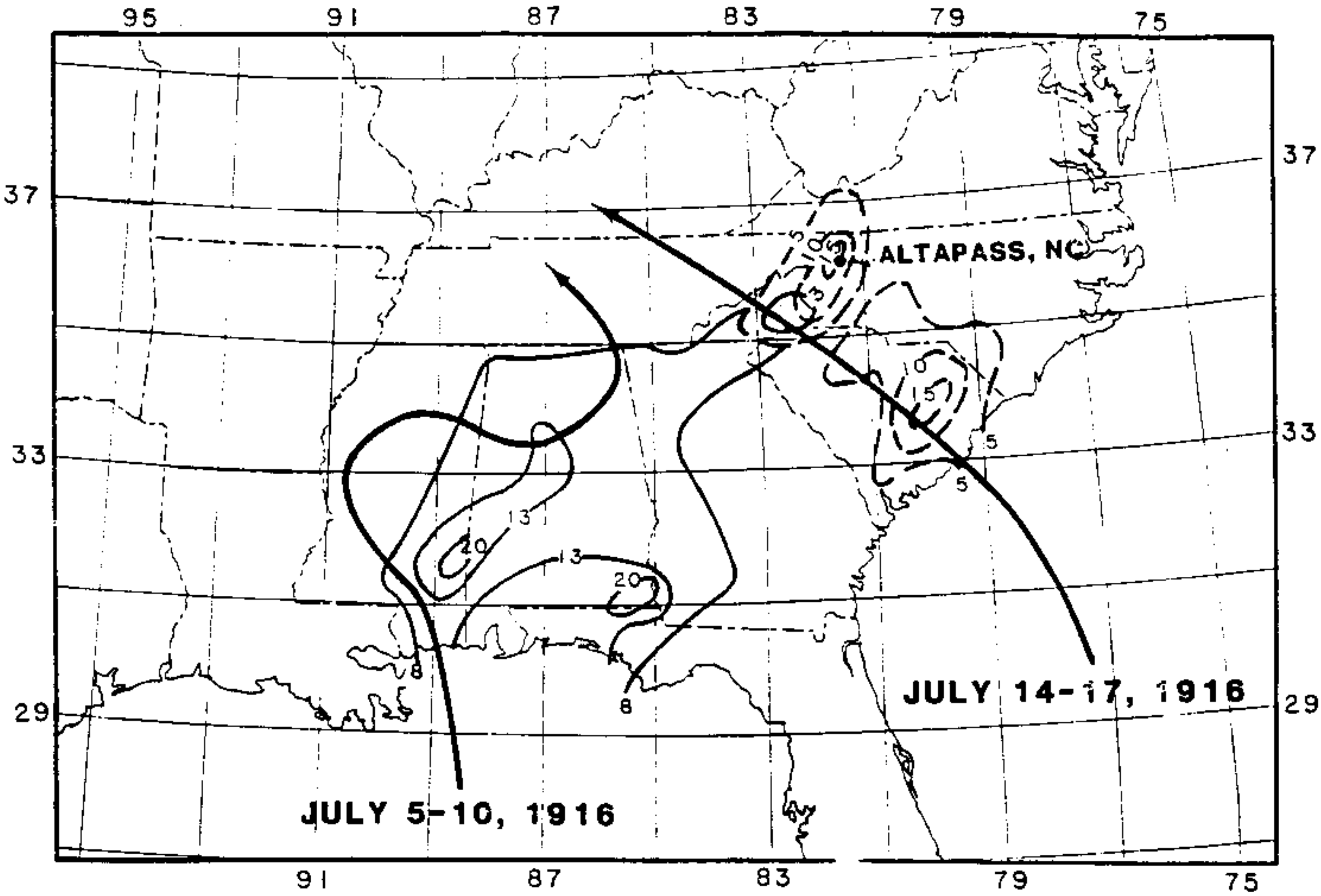

Figure 111.--Isohyetal patterns and storm tracks for storm centered at Altapass, NC, July 14-17, 1916, and the same information for the storm that occurred on July 5-10, 1916, in Alabama, Georgia and the Carolinas.

antecedent rainfall as the magnitude of the 3-day rainfall increases. There is one point which is above this trend line. An enveloping line (dashed) passing through this point with the same curvature and parallel to the trend line would show an antecedent rainfall of less than 30 percent for maximum 3-day rainfall equivalent to the PMP.

7.3.3.2 Guidance From Areal Storm Rainfall Events. "Storm Rainfall" (U.S. Army 1945-) was searched for the cases where "pairs" of heavy rainstorms occurred near the same location. The most important storms were determined and some discussions concerning them are as follows.

7.3.3.2.1 July 1916 storms in North Carolina and Tennessee. One of the more intense storms in the southeastern United States was centered at Altapass, NC on July 14-17, 1916. Figure 111 shows the storm track and isohyetal pattern from this storm, and also the storm track and isohyetal pattern for the storm prior to the Altapass, NC storm. There were two major centers in the July 14-17 storm, one in coastal South Carolina and the other near the South Carolina-North Carolina border. The antecedent storm was centered in coastal Mississippi, Alabama, and northwest Florida. A secondary rainfall center occurred in the mountains of the North Carolina-South Carolina border region as the storm center continued its erratic movement northward and crossed into Tennessee. These two July 1916 rainfall events were both of tropical origin. The first storm was reduced to a tropical depression (dissipation stage) at the time rain fell over North Carolina. The second storm was still a tropical storm when it passed through the mountains of North Carolina. The heavier rainfall in the Carolinas is in each case a combination of the orographic intensification on the slopes of the mountains and the vertical motion associated with the tropical cyclone. The primary storm produced over 23 in. at Altapass during a 3-day period, July 14-17. The 3 days between this and the earlier storm, the 10th, 11th and 12th, was a relatively dry period averaging 0.1 to 0.2 in. per day.

HMR No. 45, figure 5-5, depicted point data from this extreme pair of large area storms nearest the Tennessee Valley. Figure 112 shows these data replotted with the antecedent rainfalls expressed as a percent of the main 3-day rain rather than as magnitude. Figure 112 indicates that as the magnitude of the 3-day rain increases, the antecedent rain, as percent of the major storm, decreases.

The trend is meteorologically realistic. The large antecedent storm utilizes available moisture and ends when drier air involved in the circulation about the storm covers the area. In these large storms, the system is generally moving and both the mechanism and the moisture supply continue a general eastward or northward movement. The larger the storm and the more complete the change to a non-storm situation, the more time is needed to reinstate a moisture supply from the Gulf of Mexico or Atlantic Ocean and to reestablish a meteorological system conducive to heavy precipitation. This trend indicates that a storm with precipitation equal to 30 percent of PMP antecedent to the PMP is conservative.

7.3.3.2.2 May 1943 storms in Oklahoma. In May 1943, two extreme storms occurred in northeastern Oklahoma. Some knowledge can be gained by examination of the rainfall associated with these two storms, but two important facts must be considered. First, the storms occurred outside the season for PMP in the Holston River basin, and second, the storms are not transposable to the watershed. The May 6-12, 1943 rainstorm centered at Warner, OK, was followed by that of May 12-20, 1943 centered at Mounds, OK (fig. 113). These two stations are the centers of the heaviest point precipitation in each storm and are located approximately 50 mi apart. The area of heaviest rainfall over significant areas, (say approximately 2,000 mi^2) was more widely separated, centered about 110 mi apart.

Although the dates for these two storms reflect a nearly continuous period of rainfall, there was a definite dry period of 5 days between the significant rainstorms. If one were to superimpose a maximum 2,000 mi^2 depth from the first storm over that of the second storm, the antecedent rainfall would be 83 percent. If only the 3-day criteria were used the antecedent rainfall would have been 23 percent.

There are two factors to assess in this storm pair. First, the centers for the 2,000-mi^2 area rainfalls were not coincident. They would have to be transposed to have occurred at exactly the same point. This requires an unspecified degree of maximization. The period between the storms was 5 days and reduction of the interval to 3 days would be another maximization. These two storms are of a type which can be transposed to western Tennessee, but is not considered realistic for the eastern part of the Tennessee Valley. Major modifications of the synoptic weather patterns and the sequence of weather events would have to be made to

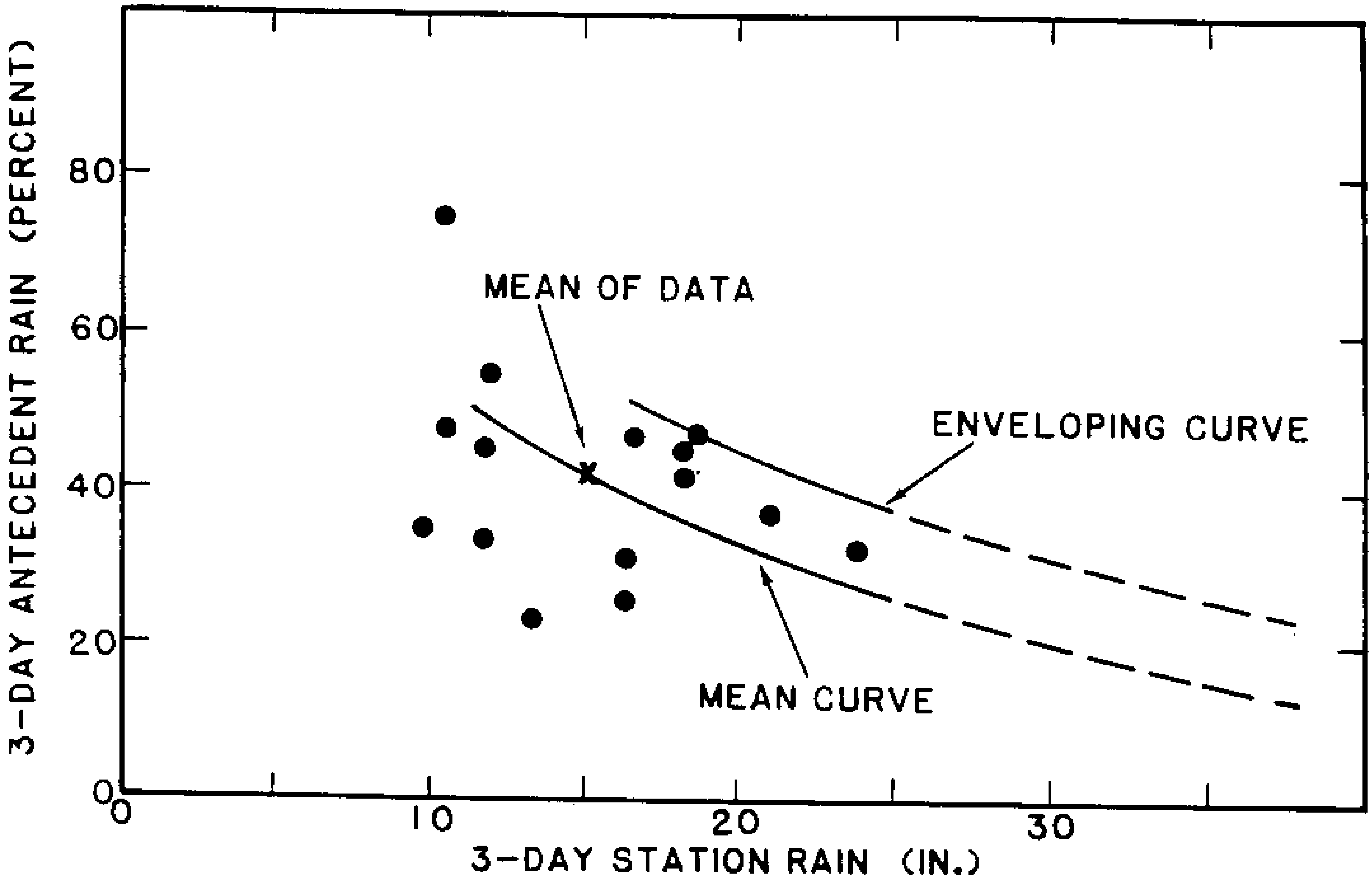

Figure 112.--Station rainfall antecedent to July 14-17, 1916, rainstorm in western North Carolina.

transpose these storms to the eastern part of the Tennessee Valley. Use of these two factors for guidance, therefore, requires judgment in determining how much maximization is involved in each of the steps. Subsequently, a decision would have to be made as to how much maximization is appropriate for the development of the antecedent storm to a PMP storm.

<u>7.3.3.2.3 **January 1937 storm in the Mississippi Valley**</u>. The record-breaking storm of January 1937 provides some information on long duration rain characteristics over fixed areas. The 3-day rains (U.S Army 1945 -) and 11- to 3-day and 15- to 3-day rain ratios for selected area sizes in this storm are listed in table 24. The 3-day rain values range from 11.0 in. for 500 mi^2 to 9.6 in. for 5,000 mi^2.

In assessing the significance of the ratios in table 24, the magnitude of the 3-day rainfall should be kept in mind. Although large, these values fall considerably short of the magnitude of PMP values of this report for summer rainfall. The resulting ratios, therefore, should be considered as too high for application to summertime 3-day PMP and for 3-day TVA precipitation.

There are two maximizations involved in the use of ratios from this storm. The first is compressing the rainfall in the period beyond the maximum 3 days into a 3-day period since the rain fell almost continuously during the 11 and 15 days. The second is in assuming that the maximum rains for the two durations were coincident in location. Even though these came from the same storm, the area covered by the maximum 3-day rainfall was not coincident with the area covered by the maximum 11- or 15-day interval.

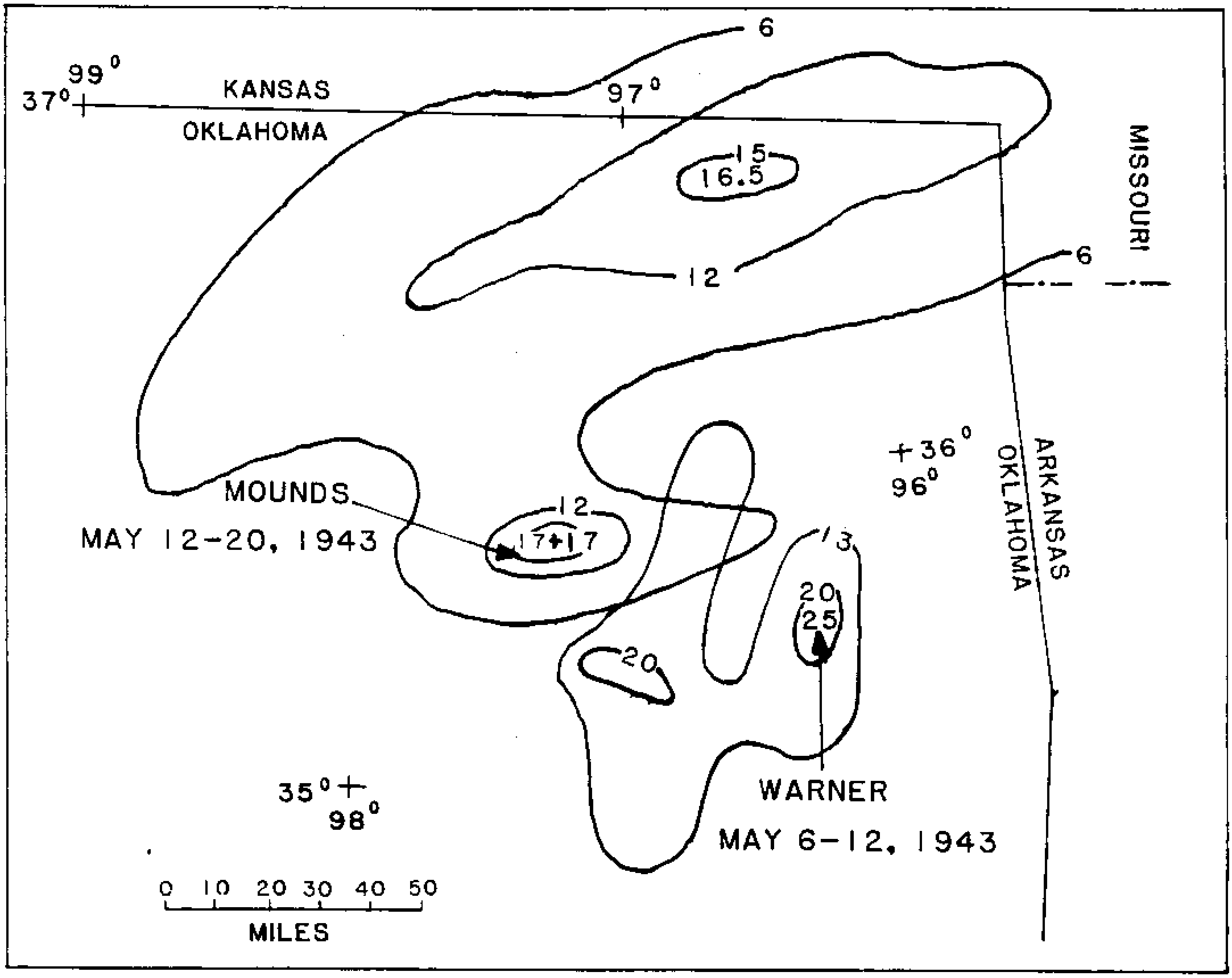

Figure 113.--Isohyetal patterns for May 6-12, 1943 storm centered at Warner, OK, and the May 12-20, 1943 storm centered at Mounds, OK.

Table 24.--Durational rain ratios in January 1937 storm

Area (mi^2)	3-Day Rain (in.)	11- to 3-Day ratio	15- to 3-Day ratio
500	11.0	1.85	1.95
1000	10.7	1.90	1.99
2000	10.3	1.96	2.08
5000	9.6	1.94	2.08

7.3.3.2.4 Guidance from rainfall antecedent to major 2,000-mi^2 area storms. A likely prototype for the PMP storm over the Tennessee River Basin is the storm associated with a remnant of a tropical storm. To understand the rainfall regime prior to major tropical storms, the 23 tropical storms that caused large rainfalls in the last 70 yr in the southeastern and eastern United States were examined. For the period prior to 1955, this information came from National

Hurricane Research Project Report No. 33, "Rainfall Associated with Hurricanes," (Schoener and Molansky, 1956.) Subsequent to 1956, data from "Tropical Cyclones of the North Atlantic" (Neumann et al. 1978, revised 1985) provided material on current tropical storms. The storm sample was expanded to add 11 extratropical storms critical to the determination of PMP for 2,000 mi^2 and 72 hr in the United States east of the 105th meridian to insure all rainfall antecedent to all major storms was considered. It should be emphasized that we are considering all major storms in the eastern United States, many of which could not be transposed to the Tennessee River basin. This is a major maximizing step and may introduce both seasonal and geographic maximization.

The locations of these storms are shown in figure 114. The circles show the location of the storm occurrence and the x's show the location of the largest areal value that occurred prior to or after the storm within 300 mi of the storm location. The numbers next to the storm location are identification numbers given in table 25 where pertinent information on each storm can be found.

1. For each storm the area was delineated within which the maximum 2,000-mi^2 rainfall occurred.

2. The daily rains for all stations in this area, from "Climatological Data for the United States by Sections" (Environmental Data Service 1896-1975) were tabulated. For guidance in determining the rain antecedent to the PMP, data for 6 days preceding and following the storm were also tabulated. The station rainfalls were averaged for each of the days, then totaled for the 6 days following the maximum average total for 3 days.

3. Station averages at the location of the storm were determined. The value used was the larger of the two 6-day amounts.

4. The data from stations within a radius of 300 mi^2 of the storm location were examined to determine similar 6-day maximums. These average depths will differ from the storm values found in "Storm Rainfall" (U.S. Army 1945 -). Complete storm studies rely on comprehensive analysis of all regular reporting stations supplemented by field surveys for additional rainfall information. This type of analysis was not available for preceding or subsequent storms. Since the detailed analysis frequently reveals rainfall centers between regular observing stations, using data from "Storm Rainfall" for the primary storm and from only the regular reporting networks for antecedent storms would artificially reduce the percentage the antecedent is of the major rain. A fairer comparison can be obtained by use of a comparable network for both storms.

Figure 115 shows the percent that the 6-day total rain preceding or following is of the maximum 3-day total for the

Table 25.—6-day 2,000-mi^2 rainfall antecedent* to major 3-day storm rainfall in the United States

Storm No.	Date	Location	No. Stns. averaged	Greatest 6-day rainfall (before) (in.)	2,000 mi^2 rain for max. 3 days				Greatest 6-day rainfall (after) (in.)	Antecedent in % of maximum 3-day rain	Storm type
					7	8	9	Total			
1	8/6-9/40	Miller Island, LA	6	4.15	3.91	9.41	14.09	27.41	.49	15	T
					17	18	19				
2	8/16-21/15	San Augustine, TX	3	2.27	7.05	6.41	5.54	19.00	2.47	13	T
					8	9	10				
3	9/8-10/21	Thrall, TX	3	.31	.17	5.88	12.30	18.35	.54	3	T
					13	14	15				
4	3/10-16/29	Elba, AL	10	.39	205	5.74	9.80	17.59	.11	2	NT
					23	24	25				
5	7/22-27/33	Logansport, LA	5	.69	3.62	10.84	2.71	17.17	.79	5	T
					15	16	17				
6	7/14-17/16	Altapass, NC	6	6.48	7.23	8.90	.37	16.50	2.26	39	T
					25	26	27				
7	9/23-10/3/29	Glenville, GA	3	.18	.99	3.47	11.50	15.96	.87	5	T
					27	28	29				
8	7/27-29/43	Devers, TX	5	.17	4.62	8.07	2.74	15.43	.07	1	T
					6	7	8				
9	7/5-10/16	Bonifay, FL	6	1.59	4.87	3.23	7.33	15.43	3.94	26	T
					27	28	29				
10	8/26-29/45	Hockley, TX	4	.10	1.15	10.64	2.79	14.58	.23	2	T
					21	22	23				
11	6/19-23/72	Zerby, PA	7	1.09	1.31	9.53	3.15	13.99	.62	8	T
					4	5	6				
12	8/31-9/6/35	Easton, MD	6	.28	.93	5.44	7.46	13.83	.53	4	T
					20	21	22				
13	9/17-26/26	Bay Minette, AL	6	.12	7.19	5.93	.10	13.22	.06	1	T
					13	14	15				
14	6/12-16/34	St. Leo, FL	5	.78	2.83	1.14	8.78	12.75	3.48	27	T
					4	5	6				
15	9/3-8/50	Yankeetown, FL	18	1.75	1.69	5.32	5.66	12.67	.55	14	
					27	28	29				
16	6/24-28/54	Pandale, TX	2	.12	.27	8.01	3.89	12.17	0	1	
					28	29	30				
17	6/27-7/1/99	Hearne, TX	4	1.37	4.89	4.26	2.84	11.99	.91	11	NT

Table 25.—6-day 2,000-mi^2 rainfall antecedent* to major 3-day storm rainfall in the United States (Continued)

Storm No.	Date	Location	No. Stns. averaged	Greatest 6-day rainfall (before) (in.)	2,000 mi^2 rain for max. 3 days				Greatest 6-day rainfall (after) (in.)	Antecedent in % of maximum 3-day rain	Storm type
					18	19	20	Total			
18	9/16-20/43	Morgan City, LA	4	3.41	4.78	4.58	2.57	11.93	1.04	29	
					29	30	31				
19	8/28-31/41	Hayward, WI	4	.48	.38	8.71	2.69	11.78	1.48	13	NT
					6/30	7/1	7/2				
20	6/27-7/4/36	Bebe, TX	4	1.90	4.75	5.94	1.05	11.74	3.05	26	
					14	15	16				
21	10/11-18/42	Big Meadow, VA	3	.90	4.19	5.70	1.83	11.72	.07	8	
					17	18	19				
22	5/12-20/43	Mounds, OK	8	.53	3.69	5.11	2.87	11.67	.95	8	NT
					8	9	10				
23	10/7-11/03	Patterson, NJ	10	.05	3.17	7.94	.34	11.45	.31	3	T
					14	15	16				
24	8/12-16/46	Collinsville, IL	9	.92	1.49	5.37	4.30	11.16	.01	8	NT
					9	10	11				
25	5/6-11/43	Warner, OK	10	.74	4.83	4.75	1.25	10.83	1.16	11	NT
					21	22	23				
26	1/5-25/37	McKenzie, TN	2	6.92	5.45	3.42	1.48	10.35	2.51	67	NT
					24	25	26				
27	8/23-26/26	Donaldsonville, LA	5	.46	.77	2.34	7.14	10.25	.92	9	T
					21	22	23				
28	10/19-24/08	Meeker, OK	5	2.82	3.14	3.92	3.13	10.19	0	28	NT
					18	19	20				
29	8/17-20/55	Westfield, MA	13	5.64	1.57	7.98	.49	10.04	.59	56	T
					3	4	5				
30	9/2-6/40	Hallet, OK	4	.44	2.10	5.56	1.91	9.57	.16	5	NT
					10	11	12				
31	8/10-15/55	New Bern, NC	6	.52	.48	2.04	7.05	9.57	4.67	49	T
					1	20	21				
32	7/18-23/09	Beaulieu, MN	5	.36	2.68	5.76	.67	9.11	1.14	12	NT
					18	19	20				
33	8/18-20/69	Tyro, VA	6	.63	.02	.20	8.19	8.41	0	7	T
					21	22	23				
34	7/18-23-09	Ironwood, MI	7	.31	1.60	4.02	2.51	8.13	.08	4	NT

*2,000-mi^2 6-day rainfall used as 3-day antecedent before or after (whichever is larger) the maximum 3-day rainfall. All rainfalls based on reporting stations in Climatological Data.

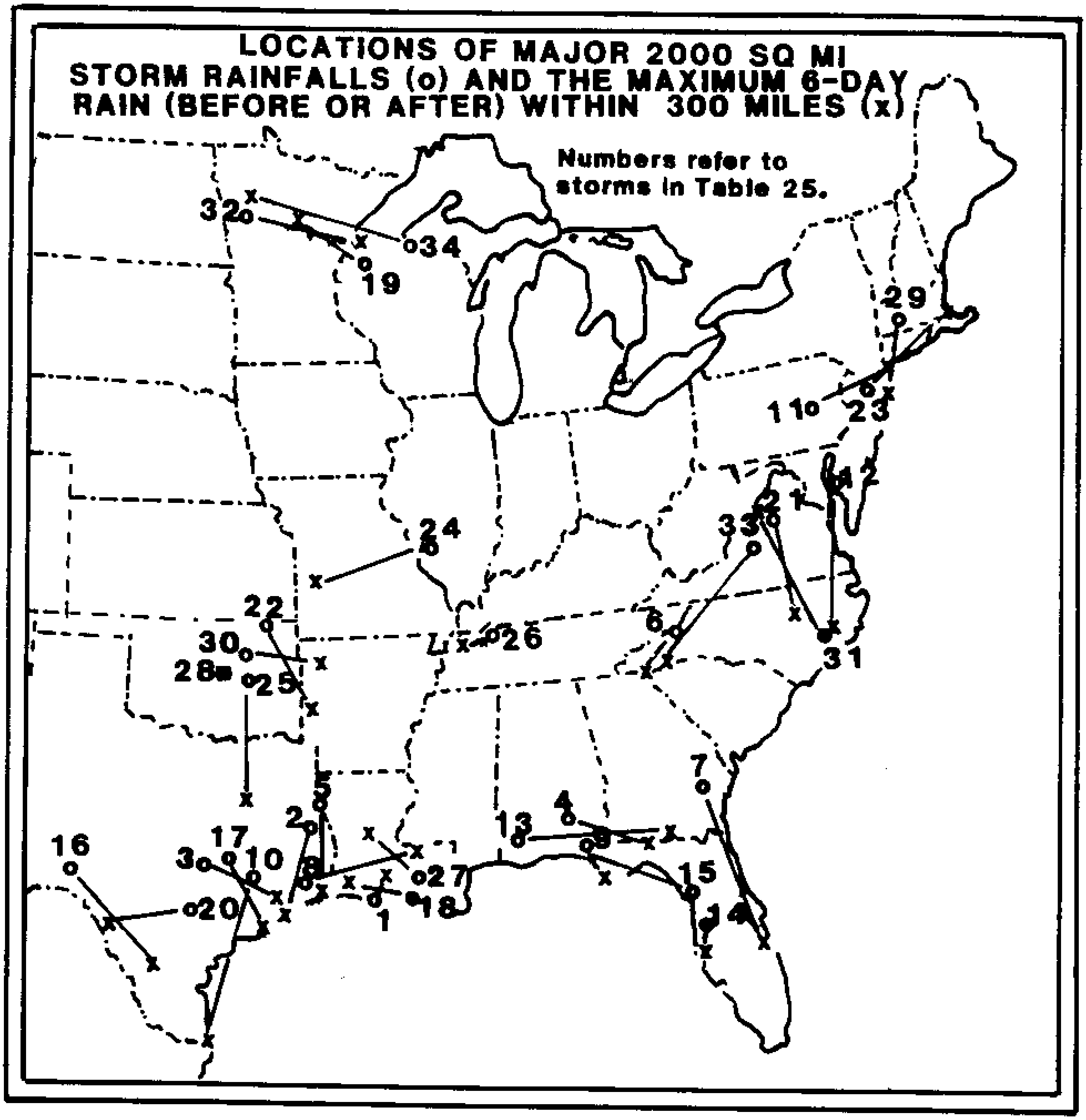

Figure 114.--Location of 34 major 2,000-mi^2 storm rainfalls and the location of the maximum rainfalls within 300 mi before or after major storm.

stations at the storm location. In each case, the 6-day rain used was the greater of the two. The same maximization is inherent in these data as in previous portions of the study. All rain in the 6-day period was included in the 3-day antecedent storm. The envelope of data for the largest storms of records shows a definite decrease in the percent the adjoining 6-day rain is of the 3-day major rain as the 3-day major rain increases in magnitude. The curve in the vicinity of 10 in., is controlled by the storm centered at McKenzie, TN in January 1937 (sect. 7.3.3.2.3). Close support is provided by the Connie and Diane tropical storms of August 1955. These storms control the envelopment of tropical storm data. The July 1916 storm at Altapass, NC (sect. 7.3.3.2.1) controls the

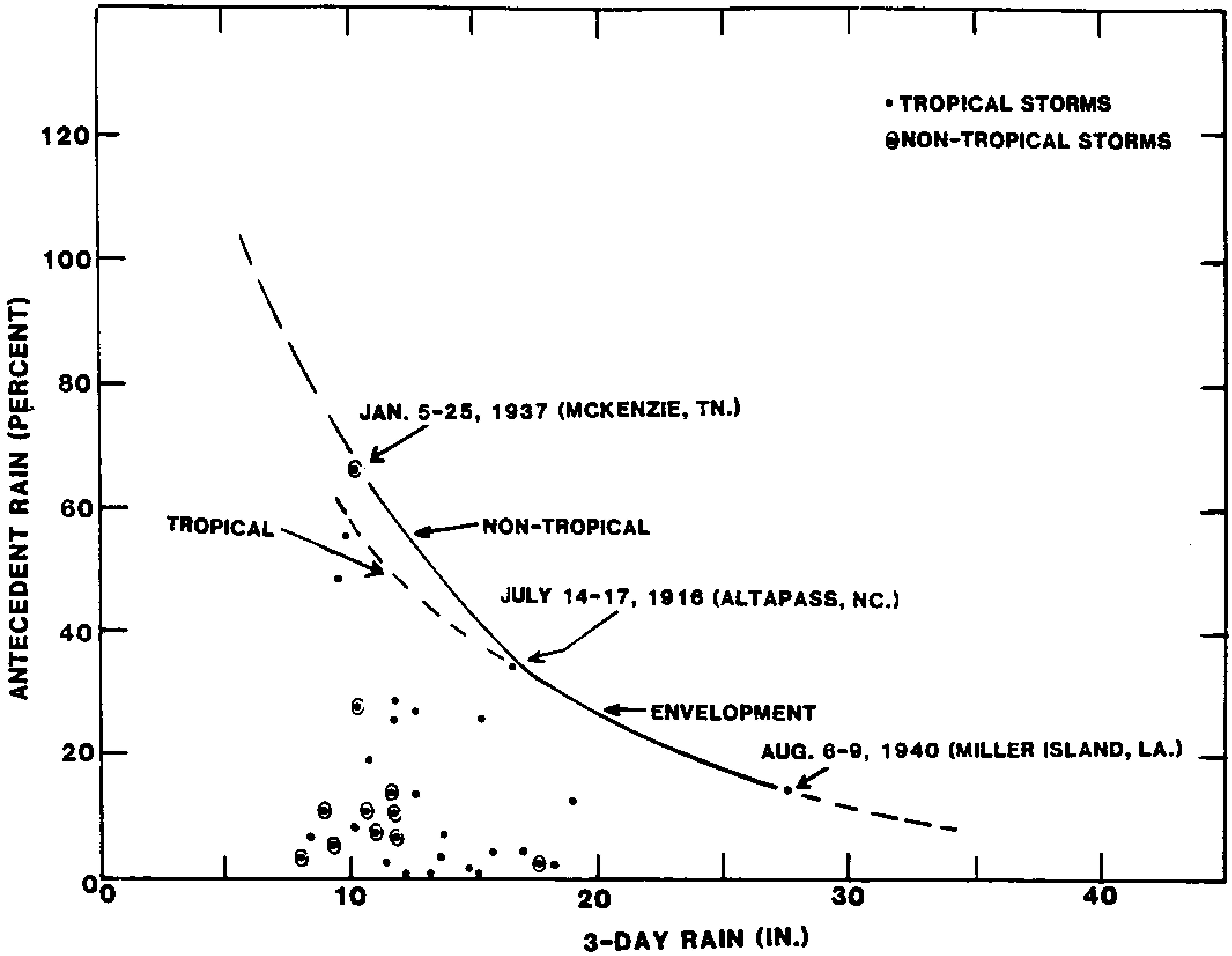

Figure 115.--Ratio of 6-day rain antecedent to 34 major eastern United States storms to major 3-day rainfall amount. Antecedent rainfall determined at location of major storm.

enveloping curves in the range between 16 and 17 in. The curve for the larger 3-day rains is controlled by the coastal storm centered at Miller Island, LA in August 1940.

The next step is to consider rainfall before or after the major storms that occurred any place within a radius of 300 mi of the location of the primary storm. This is a transposition of the rainfall from a secondary storm center to a location of the primary storm. The 300-mi radius is arbitrary but it provides an ample margin for storm transposition. We are considering a region of over 280,000 mi^2. Figure 116 shows an example of this method of storm determination. The primary storm was centered at Collinsville, IL on August 14-16, 1946, storm 24 in table 25. The maximum 3-day rainfall total was 11.16 and the average 6-day rainfall before or after was

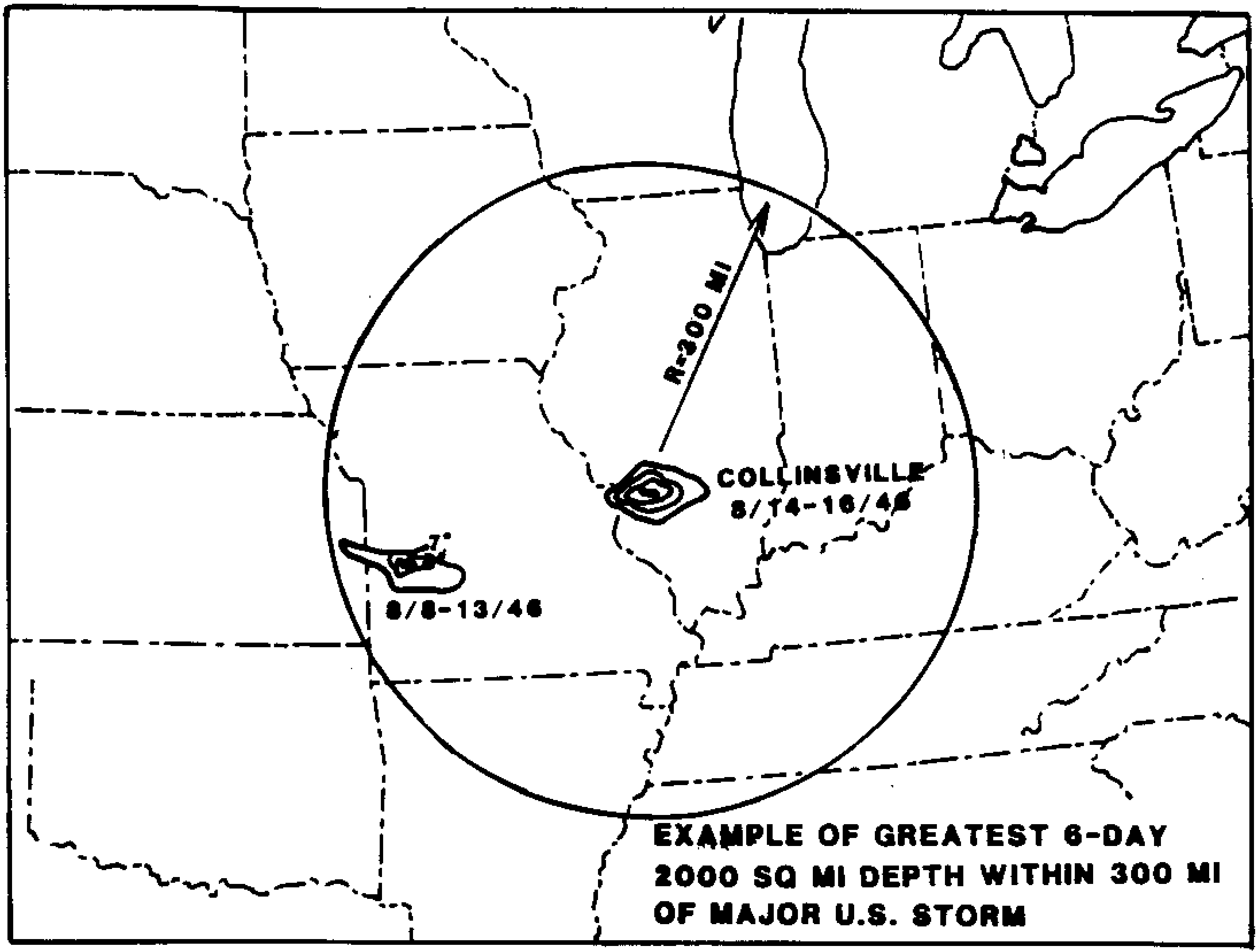

Figure 116.--Example of selection of antecedent storm within 300 mi of major storm location.

0.92 in. at the storm center. A circle of radius of 300 mi includes western Tennessee, and Kentucky, Illinois, nearly all of Indiana, southern Wisconsin, southeastern Iowa, and nearly all of Missouri and northeastern Arkansas. If this 280,000-mi^2 region is considered, a larger storm can be found. This largest rainfall antecedent to the Collinsville storm occurred in western Missouri on August 8-13, 1946, and totaled 7.6 in.

Table 26 provides information on the antecedent rainfall within 300 mi of the major storm rainfall centers previously considered. The same storm identification numbers are used as in table 25. Figure 117 shows the percent that the 6-day total rainfall preceding or following is of the maximum 3-day total. This plot is very similar to the plot shown in figure 115 except that in each case we have considered the maximum rainfall that occurred in any location within 300 mi of the storm center, rather than the rainfall antecedent to the storm at the location of the storm. The curve for the larger 3-day precipitation is again controlled by the July 1916 storm at Altapass, NC and the August 1940 storm centered at Miller Island, LA. At the other end of the curve, approximately

Table 26.—6-day 2,000-mi^2 rainfall within 300 mi antecedent to major storm rainfall in the United States

Storm No. 1	Greatest 6-day 2,000-mi^2 Depth Within 300 mi (in.)	Date of Greatest 6-day Rainfall	No. Stations Used for 6-day Avg. Depth	Location of Greatest 2,000-mi^2 6-day Rainfall (Lat.°N)	(Long.°W)	Antecedent in % of Maximum 3-day Rain
1	5.9	8/1-6/40	5	30°13'	92°01'	22
2	5.1	8/11-6-15	3	29°18'	94°50'	27
3	3.1	9/2-7/21	3	29°21'	95°01'	17
4	3.6	3/16-21/29	4	30°37'	83°55'	20
5	5.9	7/17-22/33	4	29°52'	93°56'	34
6	9.8	7/9-14/16	5	35°03'	83°12'	60
7	10.1	9/19-24/29	4	27°25'	80°19'	63
8	2.4	7/21-26/43	3	30°41'	90°44'	16
9	5.6	6/30-7/5/16	3	29°44'	84°59'	36
10	5.2	8/21-26/45	3	26°04'	97°12'	36
11	8.4	6/15-20/72	11	41°12'	73°12'	60
12	4.0	9/7-12/35	3	38°46'	76°04'	29
13	2.6	9/14-19/26	3	30°52'	83°20'	20
14	5.6	6/8-13/34	3	27°58'	82°32'	44
15	14.2	8/29-9/3/50	5	30°10'	85°40'	112
16	4.4	6/21-26/54	3	27°52'	98°37'	36
17	4.3	7/1-6/99	5	29°02'	95°48'	36
18	6.8	9/12-17/43	9	30°00'	92°47'	57
19	2.6	8/23-28/41	5	47°13'	93°36'	22
20	8.0	6/24-29/36	4	28°43'	100°30'	67
21	6.3	10/8-13/42	6	35°23'	78°00'	54
22	7.0	5/11-16/43	6	35°00'	94°00'	60
23	2.2	10/11-16/03	9	41°53'	70°55'	19
24	7.6	8/8-13/46	9	38°12'	94°02'	68
25	6.2	5/3-8/43	4	32°20'	96°10'	57
26	8.7	1/15-20/37	4	36°16'	88°43'	83
27	2.8	8/27-9/1/26	3	31°19'	92°33'	28
28	5.8	10/15-20/08	3	35°30'	96°54'	57
29	9.5	8/12-17/55	20	40°48'	73°48'	94
30	1.7	8/28-9/2/40	9	36°06'	94°12'	18
31	11.9	8/13-18/55	6	38°31'	78°26'	124
32	1.9	7/22-27/09	4	46°42'	92°01'	21
33	3.6	8/21-26/29	8	35°16'	82°42'	42
34	5.2	7/15-20/09	4	47°34'	95°46'	64

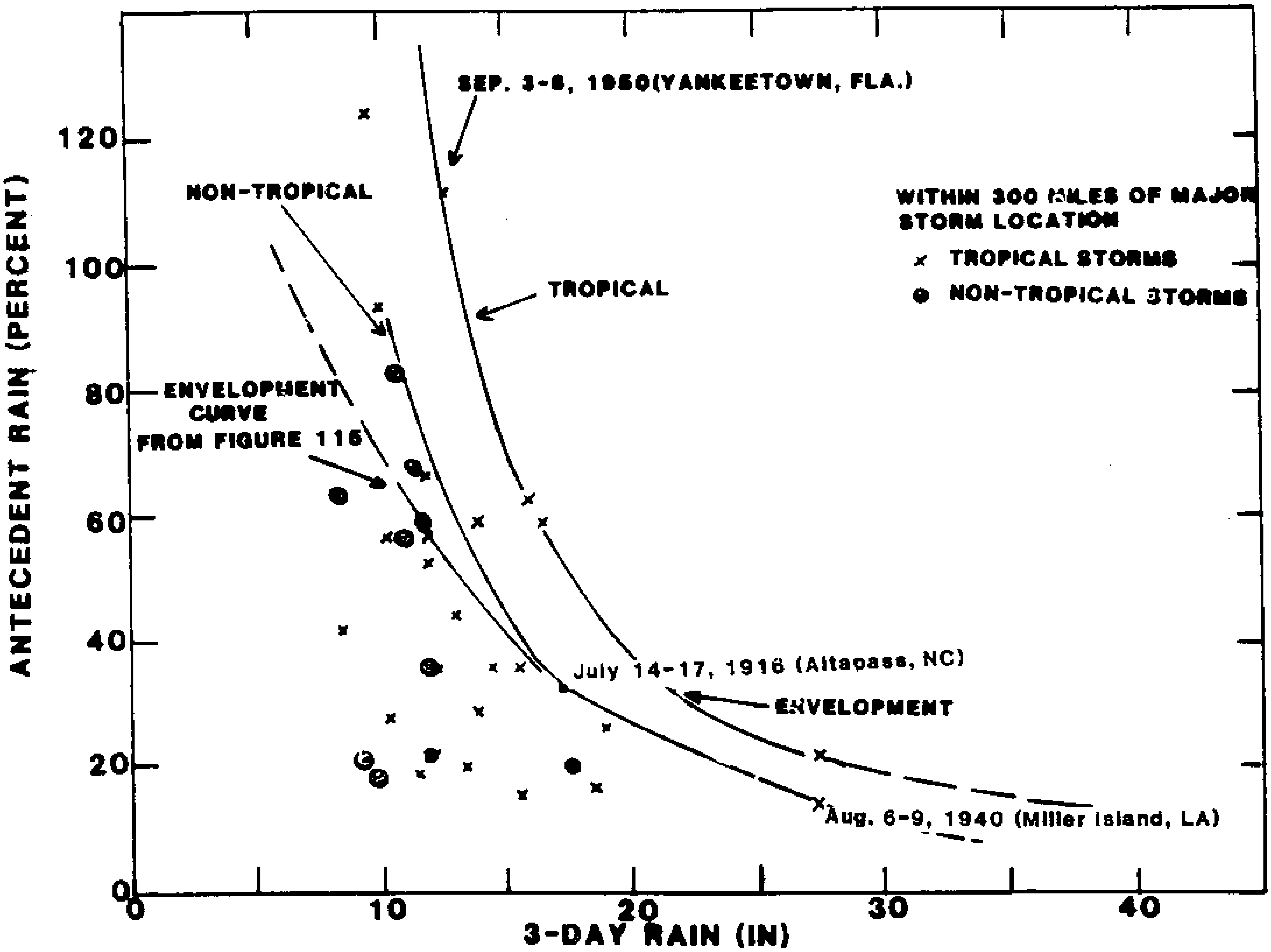

Figure 117.--Ratio of maximum 6-day rain within 300 mi antecedent to 34 major eastern United States storms.

12 in., the curve is controlled by the September 3-8, 1950 storm at Yankeetown, FL. This very high percentage results from an earlier tropical storm, hurricane Baker, that made a landfall near Pensacola, FL on August 30, 1950.

The curve from the envelopment of the antecedent storm at the location of the major storm (fig. 115) is also shown on figure 117. Though the envelopment curve for storms within a radius of 300 mi is moved upward, increasing percentages with the same maximum 3-day rainfall, the same trend of decreasing antecedent rainfall percentages with increasing 3-day rain totals is evident, as in the earlier curves. The differences between the envelopment of antecedent rainfall within 300 mi and of the storm location is greatest at the smaller magnitudes. The two curves tend to converge for the larger storms. Although this study was done for 2,000-mi^2 basins, it applies to basin areas up to 3,000 mi^2 as well.

7.3.4 Magnitude of Antecedent Storm Five Days Prior as Percent of Main Storm

For several of the data sets analyzed previously for the 3-day dry period, an analysis was also conducted based on a 5-day dry period. The purpose of these studies was to determine if storm experience indicated a significant difference in antecedent rainfall magnitude for a longer dry interval. In each of the data sets considered, the 8 days adjoining or surrounding the maximum 3-day period were determined.

7.3.4.1 Ratio of 10- and 11-day 100-yr to 3-day 100-yr Rainfall. The analysis (fig. 107) of 9-day to 3-day 100-yr ratio was based on computations for 16 points in and surrounding the Tennessee River drainage. The average 9- to 3-day ratio was 1.33. Miller (1964) also provides charts for determining 10-day 100-yr rainfall. The average ratio for the same 16 points between 10- and 3-day amounts at the 100-yr recurrence interval is 1.37. Although 11-day amounts are not provided and cannot be determined with exactness, a reasonable approximation can be obtained by extrapolation of the durational diagram from Weather Bureau Technical Paper No. 49 (Miller 1964). These estimated values would permit computation of an average 11- to 3-day ratio (3-day main storm, 5 dry days and 3-day antecedent storm). This estimated average ratio is 1.42.

The 10- and 11- to 3-day ratios are slightly larger than the 9- to 3-day ratio. It would indicate that adding 2 additional "dry" days does not significantly increase the antecedent storm. This procedure would add an additional 9 percent to the ratio developed from 9- to 3-day ratio values. It must be remembered that these ratios also include the maximizations of; 1) an independent data series; 2) no dry days required in the adjacent rainfall, and 3) that the 3-day 100-yr does not necessarily occur within the 10- or 11-day, 100-yr period.

7.3.4.2 Eight-Day Rain Adjacent to Maximum Annual 3-Day Rain. Rainfall for 250 stations in eastern Tennessee and western North Carolina used in the previous section for a 3-day dry interval was reexamined. The same procedure was used as for the 6-day adjoining rain except now 8-day rainfall adjoining or surrounding the annual maximum 3-day rain was determined. The results categorized as before are shown in figure 118. In contrast with data for the 6-day adjacent rain (fig. 108), we see a relatively large increase in the percent the adjacent rain is of the maximum 3-day rain for the smaller rains -- nearly 60 percent for 3-day rain up to 4 in. The antecedent rainfall again decreases as the magnitude of the maximum 3-day rain increases and is 34 percent for the 3-day amounts greater than 6 in. As with the similar study for 6-day antecedent rain, extrapolation to PMP magnitude would indicate smaller ratios. The extrapolation would give between 25 and 30 percent.

The maximization of selecting the maximum 8 days around the 3-day storm and assuming that all the rain is compressed into a 3-day period with 5 intervening dry days apply to this data. The compression of the rain from 8 days into a 3-day storm and a 5-day dry period is a greater maximization than the similar compression for the 6-day adjacent rain. This is because we are assuming all the rain that fell in the 5 intervening days, rather than the 3 days, fell within the 3-day storm.

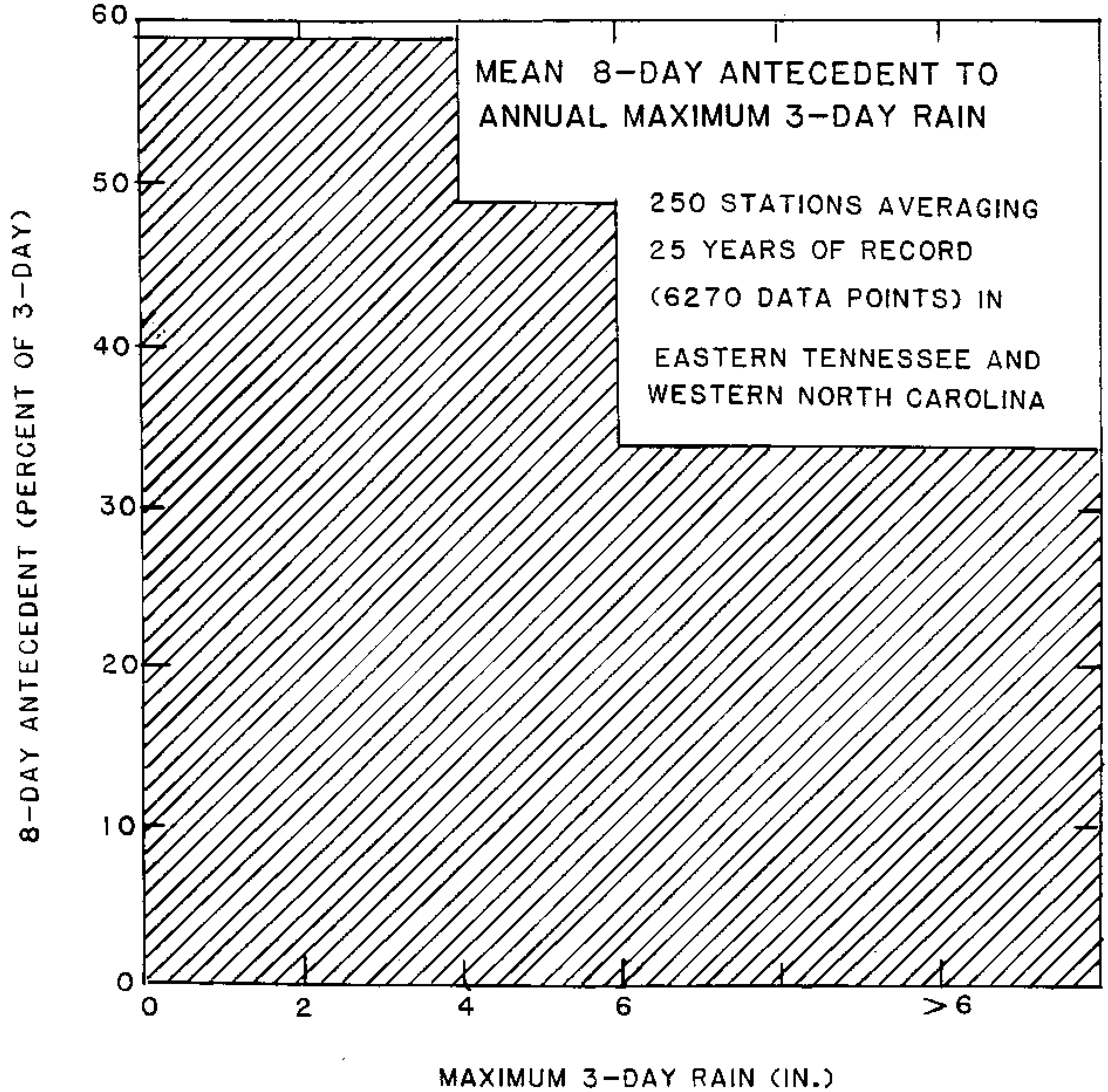

Figure 118.--Average ratio of 8-day rain adjacent to maximum 3-day rains for 250 stations in eastern Tennessee and western North Carolina.

7.3.4.3 Station 10- and 11-day Rains of Greater Than 5 and 5.5 in. Data for Memphis, TN; Asheville, NC; Birmingham, AL; and Louisville, KY were examined for the months of June to October for the period 1912-61. In this 50-yr period all 10-day rain greater than 5 in., and 11-day rains greater than 5.5 in., were selected. There were 58 and 43 cases, respectively. The analysis procedure was the same as that used for the 67 maximum 9-day amounts, and the results were similar. As the magnitude of the 3-day rain increases, the percentage of the adjacent rain was of the maximum 3-day rain decreases. For the 10-day amounts the percentage decreases from 68 to 25 percent (fig. 119), and for the 11-day amounts from 88 to 30 percent (fig. 120). These percentages are only slightly higher than for the 9-day duration (fig. 109). The results of this data also indicate only a slight increase in the magnitude of the antecedent storm as the dry interval increases from 3 to 5 days. The maximum observed 3-day rain was 12.27 in. The 10- and 11- to 3-day ratio for this storm was 1.26 and 1.31 percent, respectively. Extrapolation of the ratio from this storm, or the trend of average ratios to the PMP magnitude, would indicate ratios of about 120 to 125 percent.

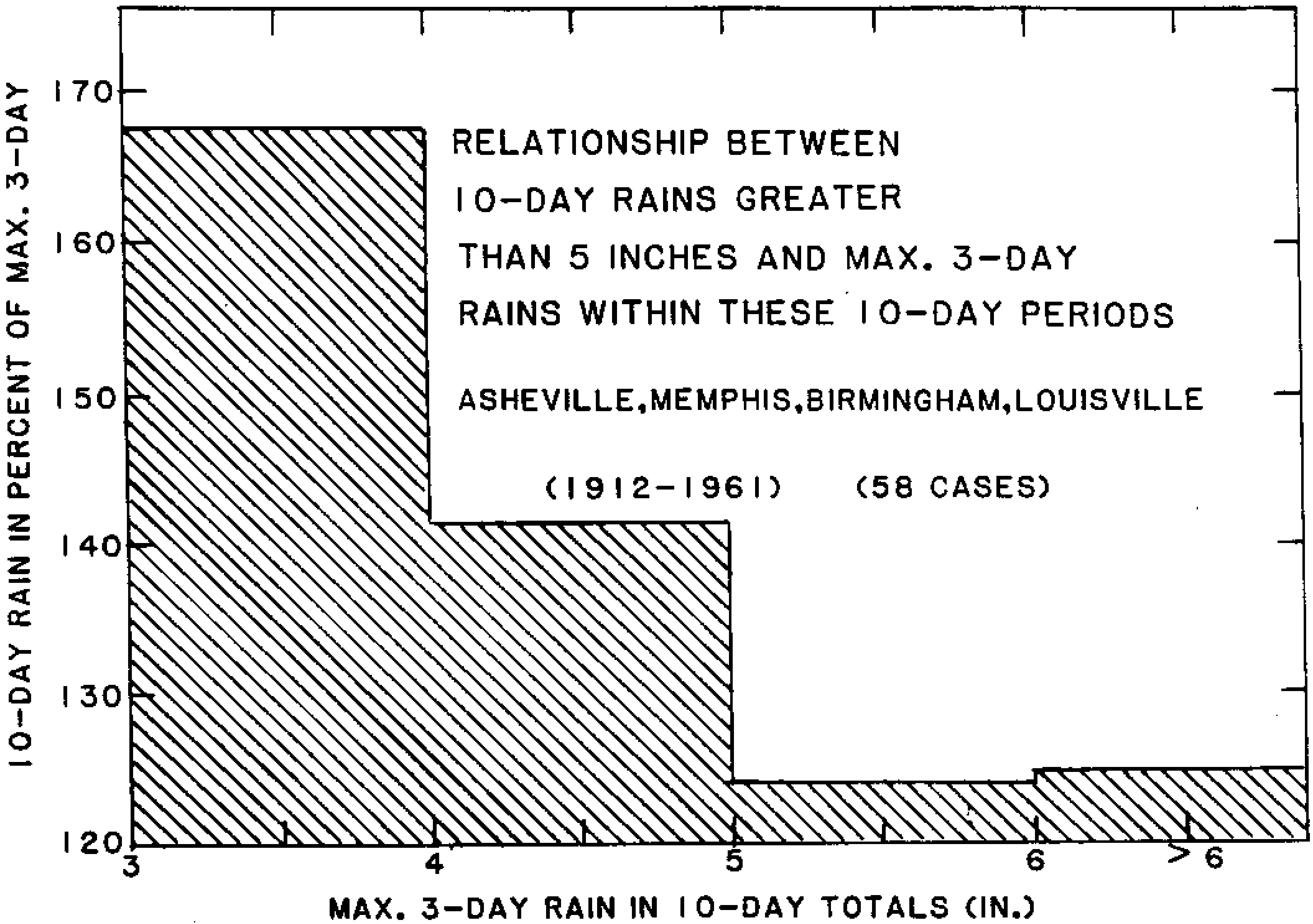

Figure 119.--Relation between 10-day rains, greater than 5 in. and maximum 3-day rains within 10-day periods. Data are for 50-yr period 1912-61 for Asheville, NC; Memphis, TN; Birmingham, AL; and Louisville, KY.

7.3.5 Tennessee Valley Authority Antecedent Rainfall Study

A separate study of antecedent rainfall associated with flood situations in the Tennessee River watershed was done by the Tennessee Valley Authority (TVA) (Newton and Lee 1969). The study was confined to the 41,900-mi^2 Tennessee River watershed. The data evaluated consisted of rainstorms which produced the ten largest floods of record at 47-gaged watersheds. The largest flood was defined by its peak discharge. The watersheds studied were selected from those having long stream gaging records with particular interest in areas from 100 to 3,000 mi^2 where 3-day storm events are likely to control. Within time and data limitations the watersheds were selected to define possible variations with watershed area and geographic location. Drainage area varied from 13 to 2,557 mi^2 with 28 of the 47 investigated being in the 100- to 1,000-mi^2 range.

The basin rainfall which produced a flood and the antecedent rainfall were estimated initially by taking an unweighted average of a selected sample of rain gages located within or near the watershed. When expanding the initial study, Thiessen weighting of all pertinent precipitation data was used to estimate basin rainfall for all added storms. At the same time a selected number of the original storm estimates were reevaluated using all precipitation data and

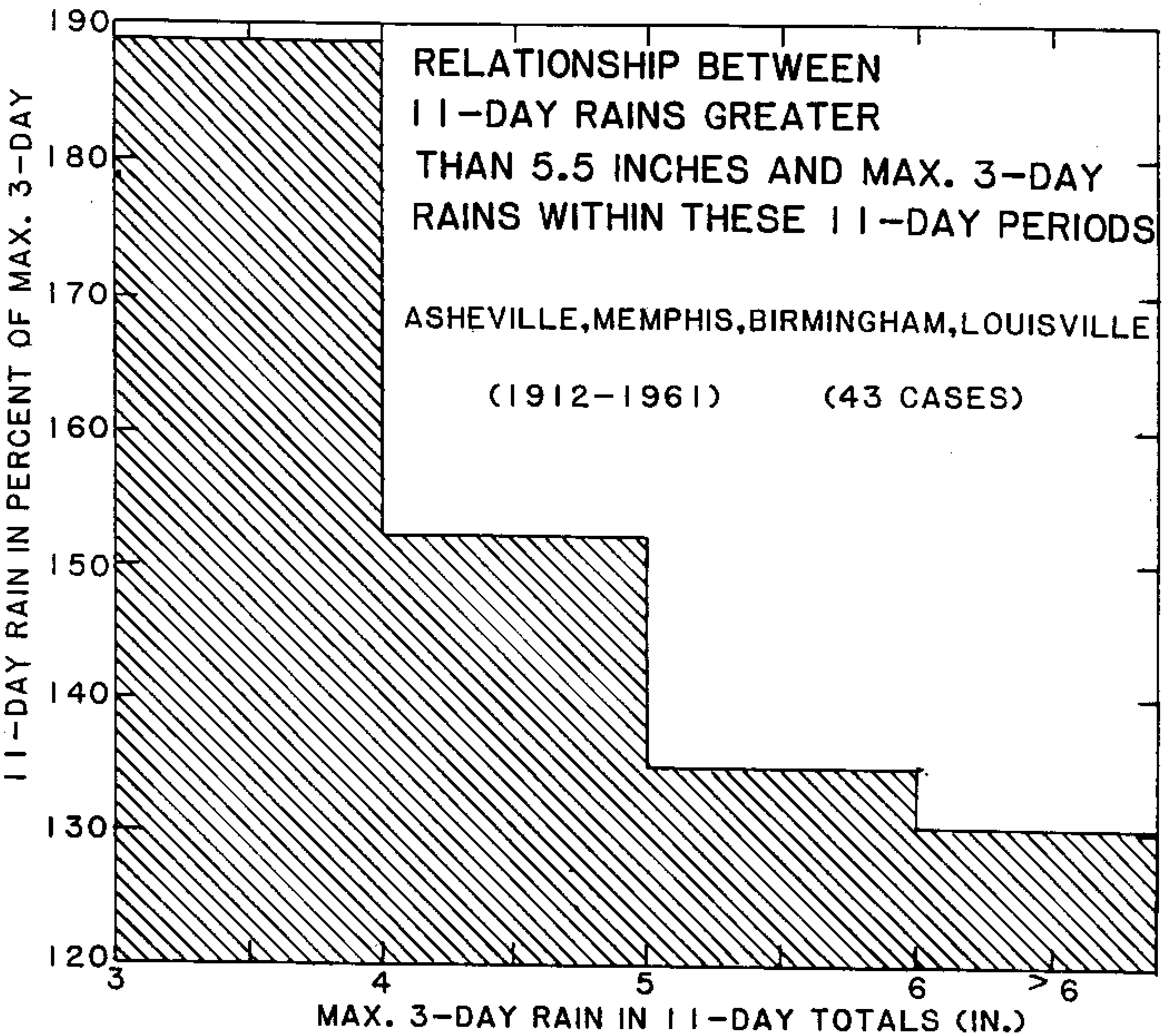

Figure 120.—Relation between 11-day rains, greater than 5.5 in. and maximum 3-day rains within those 11-day periods. Data are for 50-yr periods 1912-61 for Asheville, NC; Memphis, TN; Birmingham, AL, and Louisville, KY.

Thiessen weights. Rainfall for 160 of the 459 floods analyzed was computed using Thiessen weights. Although Thiessen weighted estimates of basin rainfall differed somewhat from the unweighted average estimates, the differences were small and did not affect significantly the results for the purposes of this study.

Storm events were divided into three categories; (1) storms of 3 or less days duration with no antecedent rainfall; (2) storms of 6- to 10-days duration with no distinct break, and (3) storms of 3 or less days duration with a distinct period and an antecedent storm. Figure 121 shows a typical example of a short storm with a distinct antecedent storm. Those events with distinct antecedent storms were analyzed to determine the average length of dry interval between

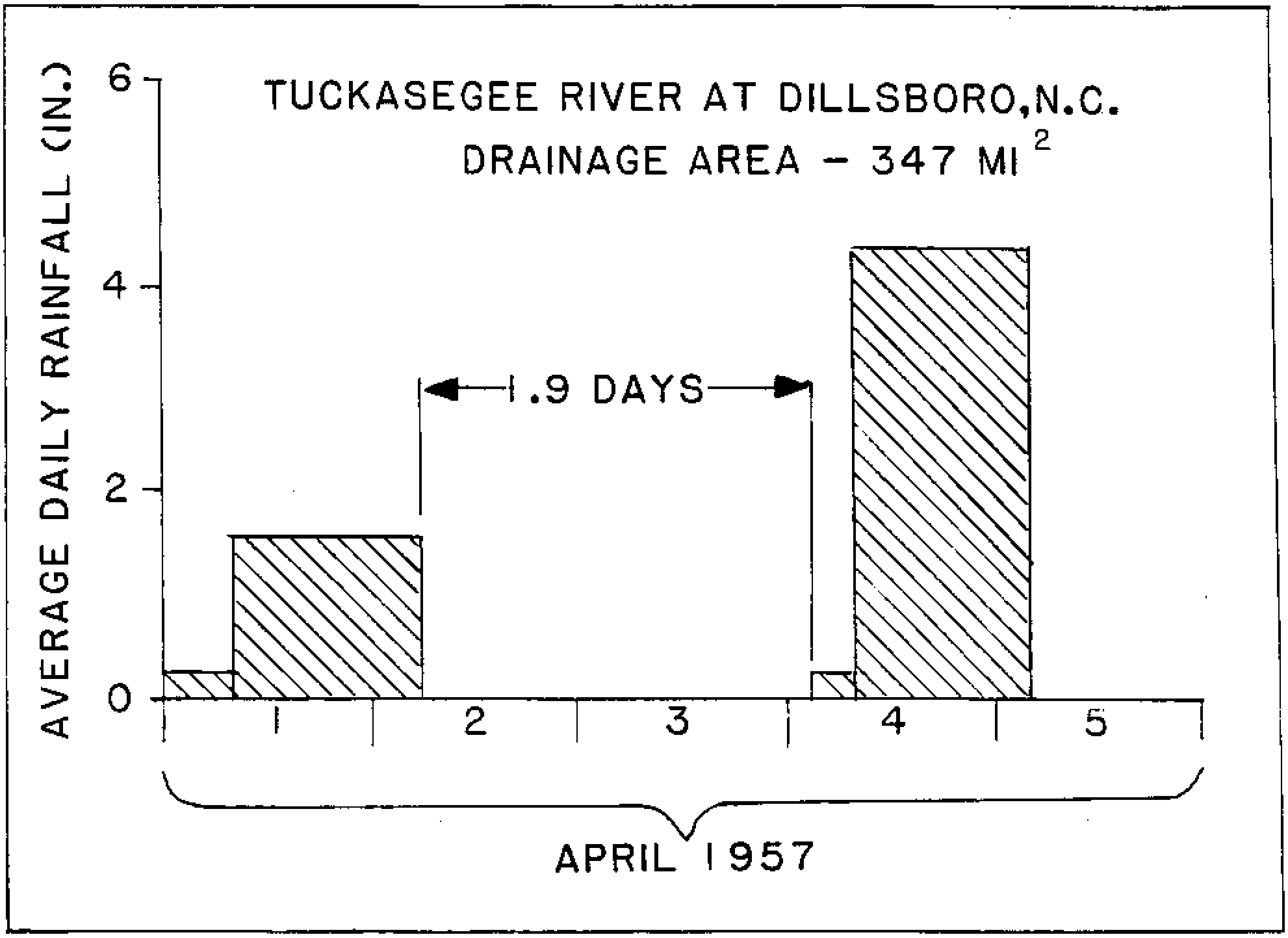

Figure 121.-- Example of storm with antecedent rain.

storms and amount of antecedent rainfall expressed as a percentage of the main storm rainfall.

Tables 27 and 28 summarize the data for the 47 watersheds. Table 27 lists data for all watersheds west of the Appalachian Divide and table 28 for those to the east. This breakdown was made because of the marked difference in the season of maximum flood occurrences. In the "eastern" basins, 48 percent of all the floods and 70 percent of the highest two floods occurred in the "summer" months of May through October. In the "western" section, only 10 percent of the floods studied occurred in the summer.

In the 22 "eastern" watersheds, 73 percent of the floods were produced by storms with antecedent rainfall and an average dry interval of 3.0 days. The median antecedent rainfall was 29.6 percent of the main storm. In the 25 "western" watersheds 77 percent of the floods were produced by storms with antecedent rainfall. The average dry interval between storms was 2.8 days, and the median antecedent rainfall was 24.4 percent of the main storm.

Table 29 shows the results when the data are stratified by season and by flood and storm magnitude. The seasonal and magnitude stratification of data shows that there is some reduction in antecedent storm rainfall for the larger floods and for the summer floods when antecedent rainfall is expressed as a percentage of the main storm.

Table 27. Antecedent storm data, western watersheds

Location of Watershed	Drainage area mi^2	Years of record	Number of floods studied	Percent in Each Case: W/out ante. rain	Percent in Each Case: No break	Percent in Each Case: With ante. rain	Antecedent Storm: Average dry interv. days	Antecedent Storm: Median depth, percent*
North Potato Cr. nr Ducktown, TN	13	33	9	22	11	67	3.7	8.4
Chambers Cr. opposite Kendrick, MS	21.1	20	9	11	11	78	2.9	25.0
Chestuee Cr. at Zion Hill, TN	37.8	18	10	0	20	80	2.7	17.4
Duck River below Manchester, TN	107	33	8	0	25	75	2.4	18.1
Sewee Cr. nr Decatur, TN	117	33	10	0	20	80	3.1	17.6
Limestone Cr. nr Athens, AL	119	28	10	10	10	80	2.6	27.7
MF Holston River at Sevenmile Ford, VA	132	26	9	0	22	78	2.4	50.2
Toccoa River nr Dial, GA	177	55	10	20	10	70	3.7	5.1
Piney River at Vernon, TN	193	42	10	10	30	60	2.7	48.8
Little River nr Maryville, TN	269	17	9	0	22	78	2.8	28.5
Powell River nr Jonesville, VA	319	36	10	10	0	90	2.4	23.4
Flint River nr Chase, AL	342	37	10	20	10	70	2.6	29.1
Shoal Creek at Iron City, TN	348	42	9	11	0	89	2.6	42.1
Sequatchie River at Whitwell, TN	384	47	9	0	22	78	2.7	10.6
Duck River nr Shelbyville, TN	481	33	10	10	20	70	2.9	30.5
Clinch River at Cleveland, VA	528	47	10	0	0	100	3.0	38.3
NF Holston River nr Gate City, VA	672	36	10	10	10	80	2.6	15.6
Powell River nr Arthur, TN	685	48	10	10	0	90	2.4	20.9
Emory River at Oakdale, TN	764	40	10	0	20	80	3.7	18.8
Nolichucky River at Embreeville, TN	805	47	10	0	20	80	3.0	32.6
Elk River above Fayetteville, TN	827	33	10	0	30	70	3.3	14.0
Duck River at Columbia, TN	1208	47	10	0	30	70	2.2	20.5
Clinch River above Tazewell, TN	1474	48	10	10	0	90	2.2	31.3
Elk River nr Prospect, TN	1784	49	10	0	40	60	2.7	12.3
Duck River above Hurricane Mills, TN	2557	42	10	0	40	60	2.9	23.7

*Percent of principal storm

Ante. = Antecedent
Interv. = Interval
W/out = Without